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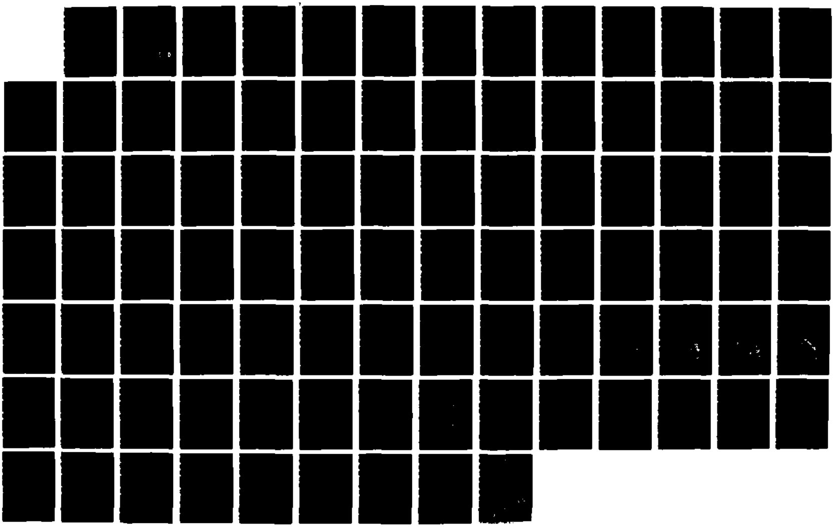

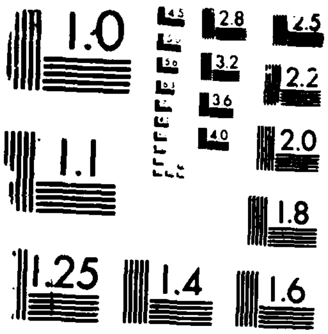

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PRE-CONVECTIVE ENVIRONMENTAL CONDITIONS INDICATIVE OF
NON-TORNADIC SEVERE THUNDERSTORM WINDS OVER SOUTHEAST FLORIDA

A Thesis

by

JEFFREY MICHAEL WILHELM

Submitted to the Graduate College of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 1987

Major Subject: Meteorology

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ABSTRACT

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Jeffrey Michael Wilhelm, 1 Lt, USAF

Master of Science, Meteorology, Texas A&M University

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ABSTRACT

Pre-Convective Environmental Conditions Indicative of Non-Tornadic Severe Thunderstorm Winds Over Southeast Florida. (May 1987)

Jeffrey Michael Wilhelm, B.S., University of Oklahoma

Chair of Advisory Committee: Dr. Kenneth C. Brundidge

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DEDICATION

This thesis is dedicated to my family, and especially to my wife, Grace. Their love, prayers, and encouragement have made the work on this thesis possible, and worthwhile.

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I wish to offer special thanks to Dr. Kenneth C. Brundidge for his constant guidance and encouragement throughout all phases of this research. I also wish to thank Dr. Aylmer H. Thompson and Dr. H. Joseph Newton for their assistance in the preparation and review of this thesis. I am grateful to the staff and faculty of the Department of Meteorology at Texas A&M University for their willing assistance throughout various phases of this research.

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A special thank you to friends in Southeast Florida who provided information and pictures illustrating how destructive and widespread non-tornadic severe thunderstorms can be in that area, while escaping any official report verifying their existence.

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1. INTRODUCTION

On May 16, 1985, thunderstorms developed over the southern Florida peninsula along convergence zones generated by the sea-breeze circulation. An innocuous thunderstorm moving towards Homestead AFB suddenly became severe, producing hail and strong gusty winds in the vicinity of the runway. Although the highest wind gust recorded was only 36 kt, the wind was strong enough to damage three secured planes, uproot a large tree, and break off tree branches. No other damage was reported elsewhere on the base, or near the base. Although radar was fully utilized by personnel at the air base and at the National Weather Service (NWS) office in Miami, no severe thunderstorm warnings were issued, nor was it anticipated, earlier in the day, that warnings would be required.

The question is whether or not synoptic-scale features can be used to indicate the potential for severe thunderstorms. Thunderstorms occur frequently over Florida, especially during the wet season of May through September. The daily development of afternoon thunderstorms during the summer becomes repetitive, but the distribution of the individual storms is different every day. Thunderstorm intensity also varies. Severe thunderstorms, or thunderstorms which cause damaging conditions at the ground due to hail, tornadoes, or strong wind gusts, develop quickly without warning. The National Severe Storms Forecast Center (NSSFC) of the NWS frequently issues severe weather watches when

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The *Journal of the Atmospheric Sciences* was used as a model for the style and format of this thesis.

it realizes that a high potential for severe weather exists over an area. Nevertheless, Florida is often ignored since upper-air data are very sparse in the vicinity of the peninsula, and daily pre-convective analyses, based upon studies of mid-latitude severe storms, may provide relatively little indication of severe thunderstorm development. As a consequence of the lack of data, and lack of organized systems around the Florida peninsula, there are very few times when severe weather watches are issued during the summer, when thunderstorm activity is greatest. Local NWS forecast offices issue special weather statements to alert the public about heavy thunderstorm activity after the thunderstorms have developed. It would be more beneficial if forecasters could alert the public of the potential for severe thunderstorms prior to their development. At this time, issuing accurate severe thunderstorm warnings in Florida is almost impossible since thunderstorm coverage can become extremely dense, and the forecaster cannot predict conditions associated with any one particular storm unless he is able to precisely analyze the storm and its internal microscale characteristics throughout its life cycle. Hopefully, single Doppler radar will someday help provide the national capability to precisely analyze the internal characteristics of a thunderstorm and its environment.

Considering that Florida experiences the most number of thunderstorms per year of any state (U.S. Department of Commerce, 1973), it is surprising that very little is known about the pre-convective conditions associated with severe thunderstorm development over Florida. The hazards of severe thunderstorms over

Florida have not been entirely realized. Although lightning is the major cause of weather-related injuries and deaths in Florida, severe and damaging winds associated with thunderstorms often cause a substantial amount of property damage (U.S. Department of Commerce, 1981a), and threaten the public more frequently than hail or tornadoes. The recognition of pre-convective features leading to severe thunderstorm winds over Florida could result in increased public awareness and preparedness, and might decrease the tragic consequences of injury and damage from these severe local storms.

The main intention of this research was to improve our awareness of atmospheric conditions preceding severe thunderstorm winds, exclusive of a tornado, and not associated with any organized large-scale disturbance, such as a front or tropical cyclone. Therefore, only those non-tornadic "air-mass" thunderstorms which produced damaging surface winds were considered. For the purposes of this study, a severe thunderstorm wind event, referred to as a severe date, was identified when surface wind damage associated with a thunderstorm was reported, or when surface winds were officially observed to equal or exceed 50 kt (57 mph or 26 m s^{-1}). Cases where severe wind gusts were unofficially observed, with no damage, did not meet the intent of this study and were not included as severe weather events. Consequently, the accurate distinction between tornadic and non-tornadic storms was imperative to this study, although it can be quite difficult to distinguish between the two types of storms based upon reports alone. Many people associate only tornadoes with wind damage, and therefore what may have been a non-tornadic storm is

reported as a tornadic storm (Doswell, 1985). A similar problem exists in cases where a funnel cloud is reported. Since funnel clouds may be confused with scud clouds, which often accompany ominous looking thunderstorms over Florida, reports of surface wind damage may be incorrectly related to reports of a funnel cloud.

a. Objective

The ultimate goal of this research was to find a foundation of meteorological features, or variables, derived from synoptic-scale observations, which suggests a high potential for non-tornadic severe thunderstorm winds over Southeast Florida. The development of storm potential criteria, which represent many of the pre-convective features evident in the synoptic environment prior to the occurrence of severe thunderstorm winds over Southeast Florida, is outlined in this report. The storm potential criteria will hereafter be referred to as a model. While the model is not perfect, it is realized that the development of a perfect model at this time would be impossible due to inadequacies in surface reports of severe storms, and the inability to account for smaller scale processes taking place which lead to the occurrence of severe thunderstorm winds over the Florida peninsula.

b. Data

Upper-air data provide forecasters with much of the information needed to make accurate analyses of the current state of the atmosphere, and then make forecasts of how the atmosphere will change. Upper-air data and hourly surface data were used to compute several factors in conjunction with the occurrence of severe thunderstorm winds. The data are available to any forecaster and provide the basis

for the calculations required in the model. Upper-air data from 1200 GMT were used since the atmosphere at this time is typically free from the contaminating effects of active convection. 1200 GMT is also the time of latest upper-air observations available to any forecaster prior to the development of any intense afternoon convection over southern Florida. Analysis of upper-air data was performed with the aid of a Harris computer operated by the Texas A&M University Department of Meteorology.

The months of May through September of the years 1977, 1980, and 1985 were initially chosen as the periods for study. 1985 was chosen since the event which initiated this study ocurred on May 16, 1985. Unfortunately, requests for 1985 upper-air data from the National Climatic Center in Asheville, North Carolina, could not be satisfied due to an extensive loss of data from tape. Alternatively, 1976, 1977, and 1980 were randomly chosen, based in part on the availability of data. Years prior to 1982 were fortuitous years to study because of the availability of data and daily NWS facsimile maps from the Texas A&M Meteorology archives. The publication Storm Data, compiled monthly by the NWS, was used to retrieve information about severe thunderstorm events. Eleven dates were identified as having non-tornadic severe thunderstorm wind events over Southeast Florida during the period of study.

Upper-air data were obtained for several stations on and around the Florida peninsula. These stations include: Key West, Florida (EYW), West Palm Beach, Florida (PBI), Tampa Bay, Florida (TBW), Charleston, South Carolina (CHS), Waycross, Georgia (AYS), and

Apalachicola, Florida (AQQ). The locations of these stations are outlined by boxes in Fig. 1. Reference to West Palm Beach includes data from Miami for the year of 1976. Although Miami was the location of an upper-air observing station prior to 1977, West Palm Beach is now the primary upper-air station for Southeast Florida. Simultaneous comparisons of upper-air data from Palm Beach and Miami have shown that the large-scale features are very similar and there are no significant discrepancies among observed variables (Lopez et al., 1984).

Hourly surface data were used to calculate area-averaged moisture convergence. The stations used include: Homestead AFB (HST), Palm Beach (PBI), Vero Beach (VRB), Patrick AFB (COF), and Ft. Myers (FMY). A line connecting these stations in Fig. 1 outlines the surface data network. Patrick AFB data were used only when data from Vero Beach were missing.

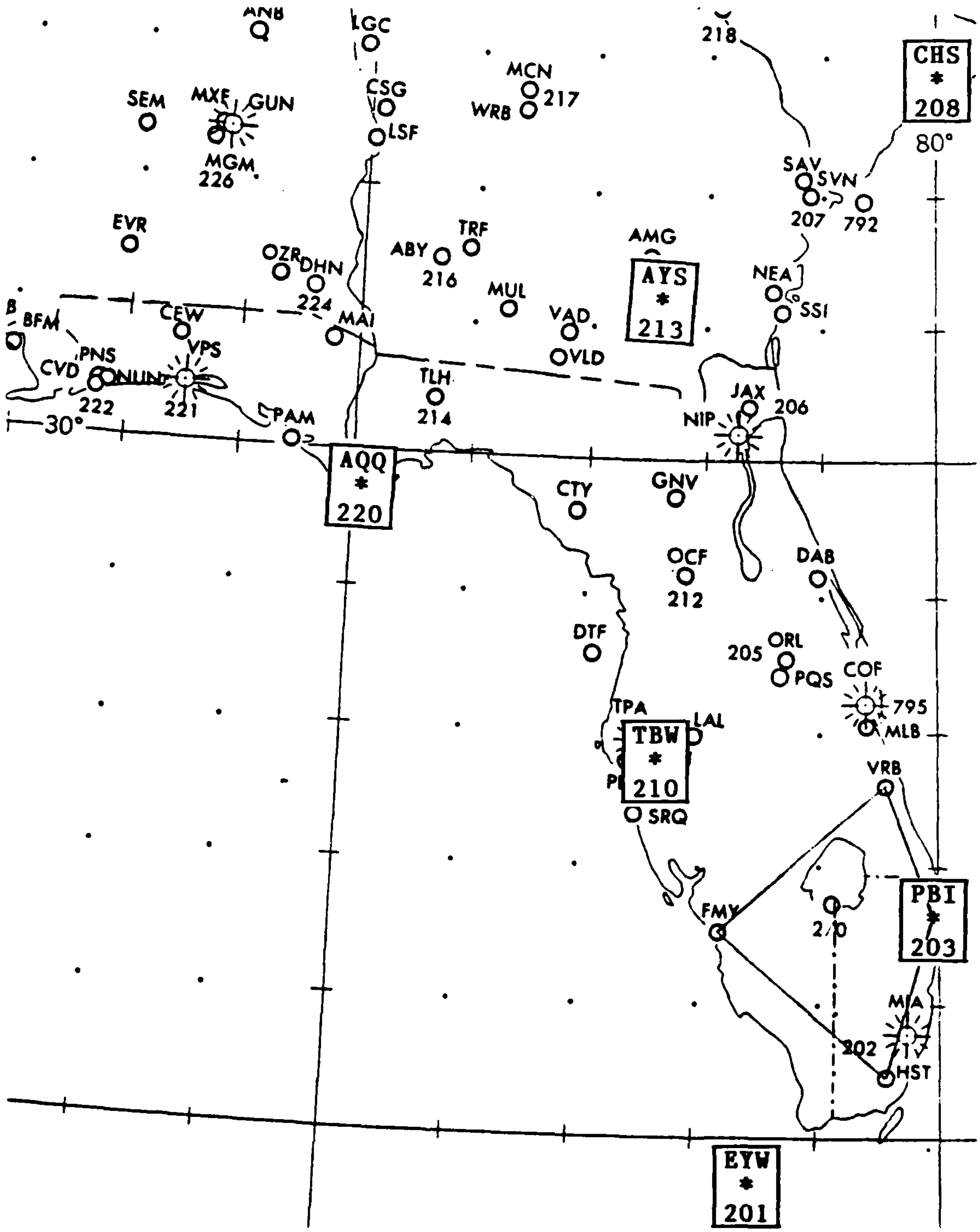

Fig. 1. Regional map of area studied. Each asterisk within a box indicates the location of an upper-air observing station for which data were obtained. Solid line outlines primary surface network used to compute surface moisture convergence. Dash-dotted line outlines three-county area of study.

2. PREVIOUS STUDIES

a. Florida Thunderstorms

Thunderstorms over Florida have a long history of investigation. One of the first major thunderstorm studies conducted over Florida was that of Byers and Braham (1949). Their observational study provided an in-depth look at thunderstorm structure and its life cycle. Results from the project indicated that the processes contributing to the development of a downdraft were very complex. Byers and Braham suggested that entrainment within the updraft of a developing thunderstorm was a very important physical process in generating stronger updrafts and downdrafts. Heavy rainfall was also suggested as an immediate precursor to strong downdrafts.

Another major project concerned with the study of Florida thunderstorms was the Florida Area Cumulus Experiment (FACE) (Woodley and Sax, 1976). Although the experiment was intended primarily as a cloud modification program, extensive research has been conducted concerning the behavior of thunderstorms over the FACE mesonetwork, exclusive of cloud seeding. Much of the research has focused on interactions between the synoptic scale, the mesoscale, and the convective scale, related to the extent of thunderstorm development over South Florida (e.g., Cooper et al., 1982; Lopez et al., 1984).

Ulanski and Garstang (1978), using data from the FACE mesonetwork, found that rainfall was usually preceded by convective-scale surface convergence. Larger, more intense storms were usually preceded by longer periods of surface convergence by as much as 90 min. They also suggested that an intense stationary thunderstorm, often found in a

Florida summertime environment with little or no wind shear with height, may require an inflow area more than twice its size to satisfy moisture needs. Unfortunately, their experiment used a convective-scale network which is not normally available to weather forecasters.

A few authors have used synoptic data to explain differences in rainfall distribution over Florida (Frank and Smith, 1968; Burpee, 1979; Lopez et al., 1984). Burpee (1979) used computations of peninsula-scale surface convergence in his study of rainfall amounts over South Florida. He found that the magnitude of the sea-breeze forcing, as reflected by the surface convergence, was similar on all days which were unaffected by synoptic-scale disturbances. However, over the entire day, Burpee concluded that there was a negative correlation between area-averaged rainfall and daily-averaged surface convergence. He stated that the results were not surprising since days with more rain would experience more downdrafts and cirrus outflow, therefore reducing the thermal forcing of the sea-breeze circulation, and peninsula-scale surface convergence. The results of his research suggest that peninsula-scale surface convergence is a consequence of events occurring at the synoptic scale. Burpee also observed that days with extensive rainfall associated with the sea-breeze circulation are characterized in the middle troposphere by cooler temperatures and more moisture than normal.

Other researchers have used synoptic data in their investigation of the relationship between surface moisture convergence and severe thunderstorms over areas other than Florida (Negri and VonderHaar,

1980). Ostby (1975) stated that surface moisture convergence values greater than 1.4×10^{-3} g kg^{-1} s^{-1} were often associated with severe weather. He also showed one case where surface moisture convergence of 2×10^{-3} g kg^{-1} s^{-1} preceded the occurrence of tornadic activity downstream by as much as 3 h. Charba (1975) showed the relative frequency of severe weather to exceed 50 % when surface moisture convergence exceeded 6×10^{-4} g kg^{-1} s^{-1}. He reported that moisture divergence was the most significant variable used in regression equations developed to make operational short range forecasts of severe weather.

The use of synoptic data and synoptic-scale features in studying the pre-convective environment of severe thunderstorms over Florida has been very limited. Charba (1979) did not include the Florida peninsula or coastal sections of the eastern United States in a system developed to produce 2-6 h forecasts of severe local storms. An obvious reason to ignore the coastal sections of the southeastern United States, including the Florida peninsula, is that severe storms in Gulf coastal states are more difficult to forecast than those occurring in the Midwest and High Plains (Galway, 1975). Charba found that in a weak, disorganized synoptic regime, characteristic of the Florida summertime environment, severe storm occurrences were typically scattered over a broad area and were poorly forecast by the system developed to aid forecasters in the issuance of tornado and severe thunderstorm watches.

Despite the lack of previous studies which characterize the pre-convective environment associated with severe thunderstorms over Florida, it should be possible to classify synoptic scale conditions

which may precede a severe weather event. Strong (1979) states that much of the energy for intense convection is manifested through an energy cascade from the synoptic scale. It would be reasonable, then, to expect the synoptic scale to exhibit some features indicative of events likely to occur on a smaller scale. In the midwest and the plains, it is common to use features analyzed from synoptic-scale maps for severe weather forecasting.

In developing a model which characterizes the pre-convective environment associated with severe thunderstorm winds, it is necessary to consider only a region of the Florida peninsula where certain measurable synoptic-scale conditions are consistently conducive to thunderstorm development over that region. Although an unstable environment and the likelihood for strong thunderstorms may be present, the location of thunderstorm activity is largely a function of the prevailing wind direction and interactions between the synoptic-scale environment and the smaller scale sea-breeze mechanism. Understanding the sea-breeze circulation is of primary importance in any study of thunderstorms over Florida. The sea-breeze circulation is generated as a result of the thermal contrast between the heated land and the cooler water surrounding the peninsula, and results in convergence zones which typically develop on most summer afternoons along the coasts of the Florida peninsula. The sea-breeze mechanism is the primary initiator of thunderstorms over Florida during the wet season of May through September. Pielke (1974) showed that regions of thunderstorm development were controlled by the sea breeze circulation and could be modified by variations of a uniform prevailing wind at the synoptic

scale. In his development of a three-dimensional model of the Florida sea breeze, Pielke chose two cases, each represented by a different prevailing synoptic wind direction. The results accurately depicted the general relationship between thunderstorm distribution and the synoptic wind field, but did not conclusively indicate any variations in thunderstorm intensity for each case.

The geography and population characteristics of Florida must also be considered in the development of a model. Much of the Florida peninsula is covered by marshes and everglades, and is not very densely populated, except along the coasts and in the north-central part of the state. A review of the 1980 census (Morris, 1983) shows only 16 of the 67 counties in Florida have a population density greater than the statewide average of 69 people per km^2. This suggests that the Florida population is concentrated in very limited areas of the peninsula. Consequently, many severe weather events may occur over unpopulated areas, and would therefore never get reported in Storm Data. The most reliable identification of dates with severe weather is obtained from areas with a high population density. For example, consider Dade, Broward, and Palm Beach Counties in southeastern Florida. Despite the fact that over half of these relatively large counties are covered by everglades, only Pinellas County, which is the second smallest county in the state, along the west coast of Florida, has a higher population density. Although storm reports from the three southeastern Florida counties are likely to be biased towards the eastern coastal sections, it would be difficult to obtain reports from any other comparably large region of the peninsula. Considering the dense population of Southeast

Florida, the dominance of the sea breeze circulation over this area, the geographically unique weather that the southeast area of the peninsula experiences, and the author's familiarization and experience with studying thunderstorms over Southeast Florida, the contiguous counties of Dade, Broward, and Palm Beach were selected for study. The three-county area is outlined by a dash-dotted line in Fig. 1.

b. Non-Tornadic Severe Thunderstorm Winds

Most studies involving severe thunderstorms over Florida have been limited to tornadic storms, and have looked at storm dynamics and multi-scale interactions within the environment. Holle and Maier (1980), and Golden (1982), suggested that mesoscale forcing is primarily involved in much of the development of tornadic activity over South Florida during the summer months. In both tornadic cases studied, researchers felt that the synoptic-scale features did not suggest a potential for tornadic activity. However, the synoptic-scale features in both cases showed some similarities, even though they didn't match synoptic conditions and environmental models indicative of mid-latitude tornadic thunderstorms. The winds aloft were light and variable, and there was very little wind shear between the lower and upper levels of the troposphere. Both cases had lifted indices indicative of an unstable atmosphere, and weak surface convergence zones were present.

Although there may be some similarities in the environmental conditions which aid in the production of tornadic thunderstorms, it is also possible to conclude that the pre-convective atmospheric conditions for non-tornadic thunderstorm winds are different from those

for tornadic thunderstorms over Florida. The damaging effect from each of these storms is the result of different physical processes and interactions taking place within the storm, and between the storm and its environment. A tornadic thunderstorm has a strong convergent area which is intensified in the area of a tornado. The tornado affects a comparatively well-defined narrow area. On the other hand, damaging surface winds produced from a non-tornadic storm are divergent areas underneath a thunderstorm which rapidly broaden as strong downdraft winds reach the surface. Damage associated with non-tornadic severe thunderstorm winds may often exceed that of a tornadic thunderstorm, especially in Florida, where tornadoes are weak and short-lived.

The environmental lapse rate over Florida is generally moist adiabatic throughout the troposphere. In this warm, moist environment, the sudden onset of damaging surface winds may be associated with a "wet" downburst. A wet downburst is defined as an area of highly divergent, straight or curved winds of damage-causing intensity at the surface, found in association with a shallow mixed layer at the surface and a moist adiabatic lapse rate above, and often concurrent with the onset of heavy rain from a thunderstorm (Wakimoto, 1985). Damaging surface winds may also be the result of straight-line winds associated with a gust front or thunderstorm outflow. Straight-line winds are usually associated with the outflow from rapidly moving thunderstorms, or may be observed at some distance away from the center of a downburst.

The physical processes within a thunderstorm producing a strong downdraft are quite complex. The most recent understanding of how the

strong downdraft and damaging surface winds are produced comes from years of experimental field research and modelling. It is widelv accepted that downdraft air is a mix of in-cloud air and environmental air entrained into the rear mid-section of a thunderstorm (Doswell, 1985; Snow, 1986). The entrainment of dry, potentially cool air causes evaporative cooling within the cloud. If the evaporative cooling occurs within a favorable layer within the thunderstorm for an extended period of time, it causes air to sink as long as the air remains cooler than the surrounding air. Initiated by falling raindrops within and at the base of the cloud, an intensifying downdraft is aided in its development by evaporative cooling. Air within a thunderstorm outflow has been shown to have originated from a mid-tropospheric layer, such as 500-600 mb, through the comparison of observed values of equivalent potential temperature at each level (Browning and Foote, 1976).

Only one study has been found which relates features of the synoptic environment to the occurrence of non-tornadic severe thunderstorm winds over South Florida. In that study, Caracena and Maier (1979) performed an analysis of a microburst which occurred in the FACE mesonetwork on 1 July 1975. A microburst is a strong downdraft inducing an outward burst of damaging winds on or near the ground with its path length less than 5.1 km (Fujita, 1978). Using a time-space conversion analysis, a 1200 GMT 500 mb meso-analysis showed equivalent potential temperature values as low as 324 K over central Florida. Miami upper-air soundings at 1200 and 1800 GMT produced a lifted index in the range of -4 to -6 and a total totals index of about 48. A mesoscale low at 500 mb was suggested to have approached

south-central Florida from the northeast. Caracena and Maier stated that as the low approached, the associated large-scale vertical motion field, the dry, potentially cool air, and intensified wind shear all contributed towards the development of a microburst. The meso-analysis of this microburst event shows how relatively minor disturbances in the mid-troposphere can spark severe thunderstorm activity.

3. ANALYSIS OF ATMOSPHERIC FEATURES

In developing a model which applies to a limited geographical area, many features were analyzed and tested. Based on experience in forecasting the weather in Florida, and results of research and analyses by other studies of severe thunderstorms over Florida (Holle and Maier, 1980; Golden, 1982), the lifted index was considered an important index to include in this study. Other stability indices were also tested and analyzed to see how they related to the occurrence of severe thunderstorm winds. Atmospheric variables, such as equivalent potential temperature, also were calculated and analyzed in an attempt to find common synoptic-scale features among all of the severe weather events.

a. Stability Indices

Various kinds of stability indices have been used to evaluate the potential for thunderstorm development, and in some cases, thunderstorm intensity. The lifted index (LI) is an appropriate stability index for use in areas where the surface is close to sea level, such as South Florida. It provides a measure of atmospheric instability, which is aided by low-level warm, moist air and relatively cool air aloft. Other stability indices include the Showalter stability index (SSI), the K index (KI), and the vertical totals (VT), cross totals (CT), and total totals (TT) indices. The total totals index is simply a summation of the vertical and cross totals indices. Since these two indices were separately evaluated, the total totals index was not evaluated. Johnson (1982) provides a concise and accurate explanation of all the indices. Two more stability indices are a modified Johnson

lag index (MJLI) and a Delta Theta-E index ($\Delta\theta_e$). Both indices were derived from Johnson's discussion of stability indices. All of the indices represent an evaluation of the thermodynamic properties of the atmosphere which are critical in forecasting the potential for severe thunderstorms in an atmosphere characterized by weak large-scale flow patterns, such as over Florida during the summer (Reap and Foster, 1975). Each stability index was calculated every day using 1200 GMT upper air data. Equations used in calculating the indices are listed in Table 1. To be included in a model, atmospheric stability indices associated with severe thunderstorm wind events were expected to satisfy previously established critical values indicative of thunderstorm development. If severe thunderstorm activity occurred when an index failed to satisfy a critical value, that index was not considered to be very valuable in forecasting the potential for severe thunderstorms, unless it consistently behaved the same way. Critical values applicable to this study are included for each index in Table 1.

Several methods have been documented and used in the past to compute a lifted index. For this study, it was desired to compute a lifted index which was as close as possible to the values listed on NWS facsimile maps for purposes of comparison. To achieve this goal, a surface temperature of 30^{o} C (86^{o} F), equivalent to afternoon temperatures in Southeast Florida during the summer, was substituted for the actual observed value. The index, developed for this study, then consists of the difference between the observed 500 mb temperature and the 500 mb temperature of a parcel lifted pseudo-adiabatically from a lifting condensation level (LCL), found at the intersection of the

Table 1. Stability index equations and respective values at which thunderstorm development is typically indicated. All values are ^{o}C.

Index	Equation	Critical Value
LI	$T_{500\ (OBS)} - T_{500\ (LIFTED\ FROM\ SFC-950\ mb\ LAYER\ LCL)}$	< 0
SSI	$T_{500\ (OBS)} - T_{500\ (LIFTED\ FROM\ 850\ mb\ LCL)}$	≤ 3
VT	$T_{850} - T_{500}$	≥ 23
CT	$T_{d\ 850} - T_{500}$	≥ 16
KI	$T_{850} + T_{d\ 850} - T_{500} - (T_{700} - T_{d\ 700})$	> 20
$\Delta\theta_e$	$\theta_{e\ MIN} - (\theta_{e\ LI} + \theta_{e\ 850})/2$	< 0
MJLI	$-11.5 - (T_{700} - T_{850}) + 2(T_{500} - T_{700} + 14.9)$ $+ 2(\theta_{e\ 850} - \theta_{e\ LI} + 3.5) - (3.0 + \theta_{e\ 700} - \theta_{e\ MIN})/3$	< 0

$\theta_{e\ LI}$: Equivalent potential temperature of SFC-950 mb layer

$\theta_{e\ MIN}$: Minimum equivalent potential temperature (throughout sounding)

mean mixing ratio of the surface-950 mb layer, and an adiabat equal to the mean temperature of the same layer. A comparison of lifted index values during June of 1977 for TBW and PBI showed that the values calculated by this method differed from the values on the NWS facsimile map by an average of only 0 to -1 ^{o}C.

Fig. 2 demonstrates the use of a scatter plot graph to evaluate the usefulness of an index in distinguishing severe from non-severe dates. Each point on the graph corresponds to respective values of the variables, listed along each axis, for all 459 days in the study. Each X represents the index values observed on a severe date. As indicated in Fig. 2, multiple plots are possible in which case a point or an X

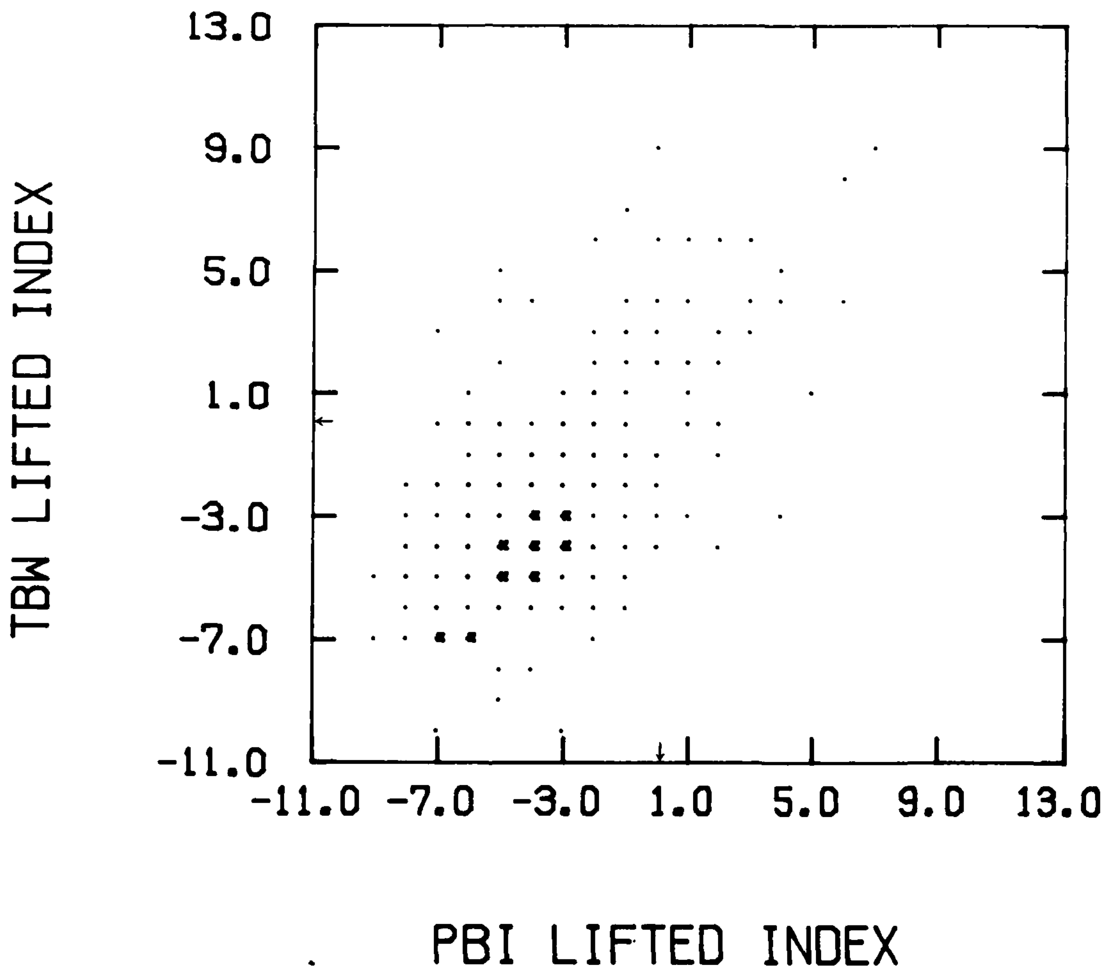

Fig. 2. Scatter plot of TBW versus PBI LI (^{o}C). Each day within the 1976, 1977, and 1980 period of study is represented by the plot of a point. Each "X" indicates a day with a report of severe thunderstorm winds. Each point or "X" may represent more than one day. Arrows indicate critical values for stability indices listed in Table 1.

may be representative of more than one date. In the case of the lifted index, points in the lower left part of the graph are representative of a more unstable environment than other points. The severe thunderstorm wind events are all associated with an unstable environment as seen in Fig. 2 by the cluster of X's at LI values less than or equal to -3 for both stations. A total of 230 of the 459 days under study are also represented by lifted indices simultaneously less than or equal to -3 at the two stations. Obviously, the lifted index cannot be used as a single indicator of severe thunderstorms over Florida. Similar values of the lifted index at both upper air stations are to be expected since this would indicate some homogeneity of the air mass over the peninsula.

The Showalter stability index is typically not as useful an index as the lifted index, since it uses the temperature and mixing ratio at 850 mb as its foundation in finding an LCL, in contrast to the use of lower-level mean values of temperature and moisture used in calculating the lifted index. Showalter stability index values of +3 or less are typically associated with thunderstorm activity. This index normally works better at locations with higher elevations. The SSI plot for TBW and PBI (Fig. 3) shows a cluster of points in the lower left hand corner of the graph, representing more unstable environments. Again, many non-severe dates simultaneously satisfy the critical value at both stations. However, the severe dates, indicated by X's, show that the previously established critical value applies to only 82 % of the severe storm cases, therefore making the SSI non-definitive for the purpose of this study.

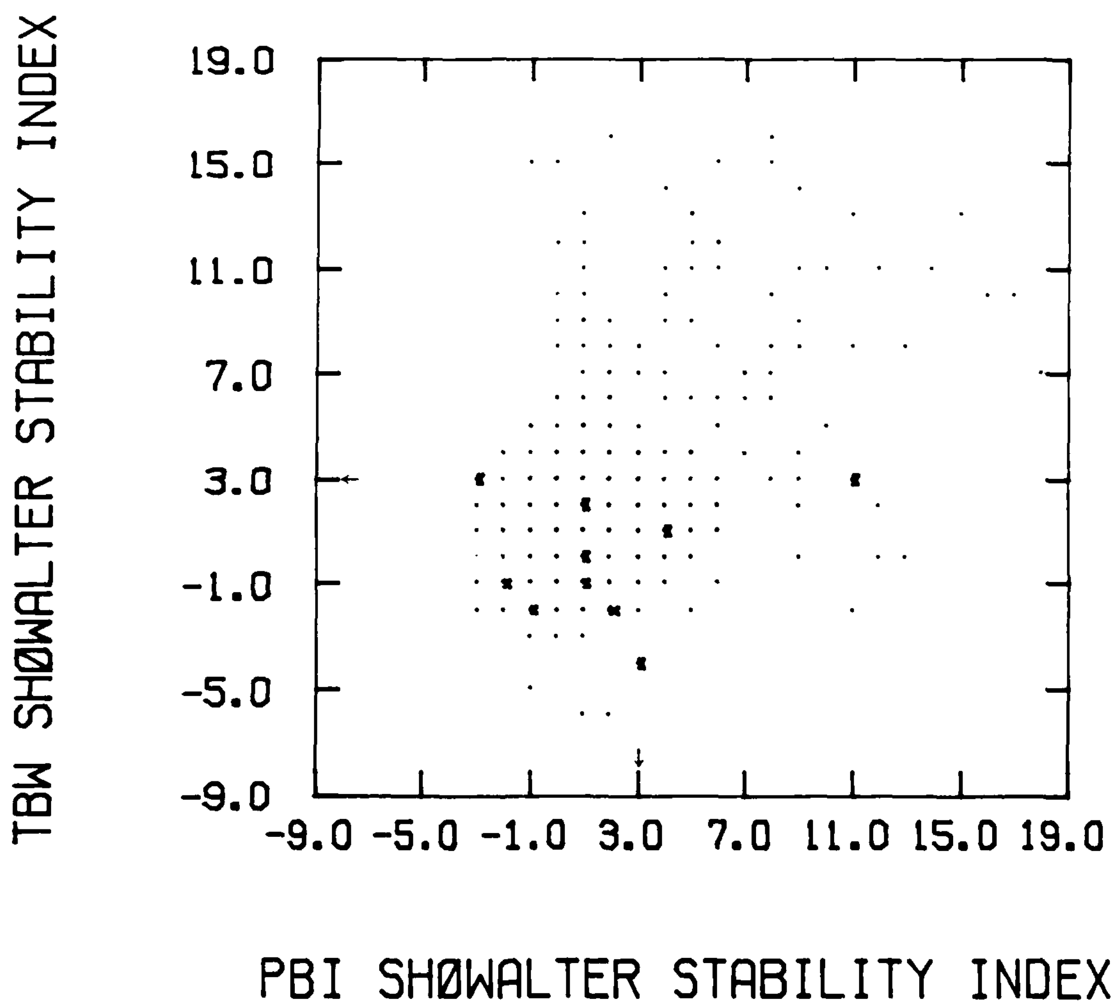

Fig. 3. Scatter plot of TBW versus PBI SSI (^{o}C). Same type of plot as presented in Fig. 2.

For the same reason that the Showalter stability index is not very useful over Florida, the cross totals index and K index are also typically not used. Both indices rely on the amount of moisture at 850 mb, and the K index also includes moisture at 700 mb for its calculation. While significant moisture may be present at 850 and 700 mb, moisture below 900 mb is more critical in the development of thunderstorms over Florida. A cross totals index of 16 or greater, and a K index greater than 20 are typically indicative of thunderstorm potential. These indices are also more useful in areas of higher elevation. Figs. 4 and 5 show scatter plots of these two indices for PBI and TBW, respectively. The cluster of points in the upper right corner is indicative of the warm, moist environment typically present over Florida. Despite the predominance of index values above their respective critical values, three severe dates did not satisfy at least one of the critical values at PBI (Fig. 4). In contrast to PBI, the cross totals and K index from the TBW sounding were found to be greater than their respective critical values of 16 and 20 on every severe weather day (Fig. 5). Although these indices weren't considered as important and significant as other stability indices, the indices from TBW were still included in the model, since they did provide some additional distinction between the days with and without reports of severe thunderstorm winds.

The vertical totals index is a stability index indicative of thermal contrasts between a lower-level (850 mb) and an upper-level (500 mb) of the troposphere, as seen by the equation in Table 1. Values of 23 or greater have usually been indicative of thunderstorm

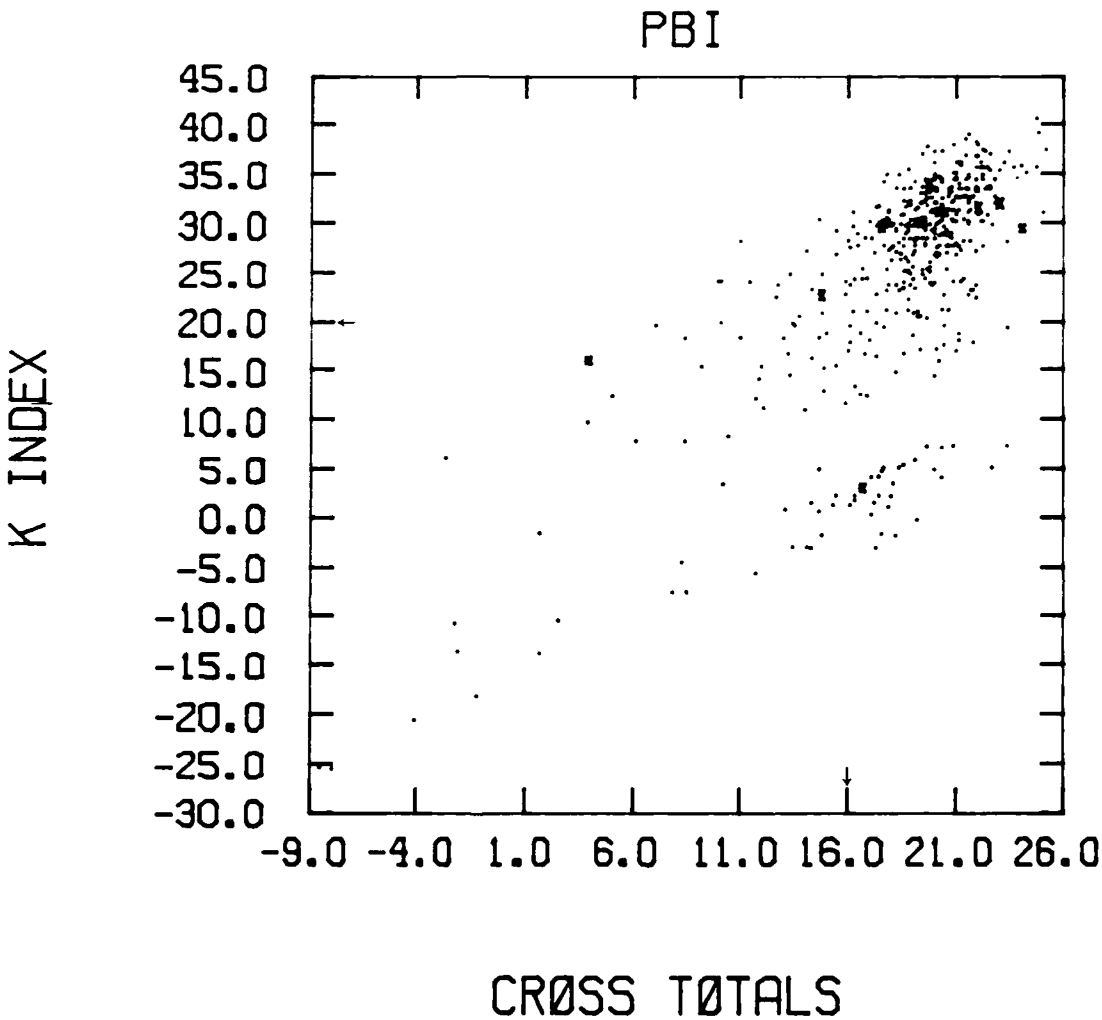

Fig. 4. Scatter plot of PBI CT versus KI. Both indices are expressed in units of ^{o}C. Same type of plot as presented in Fig. 2.

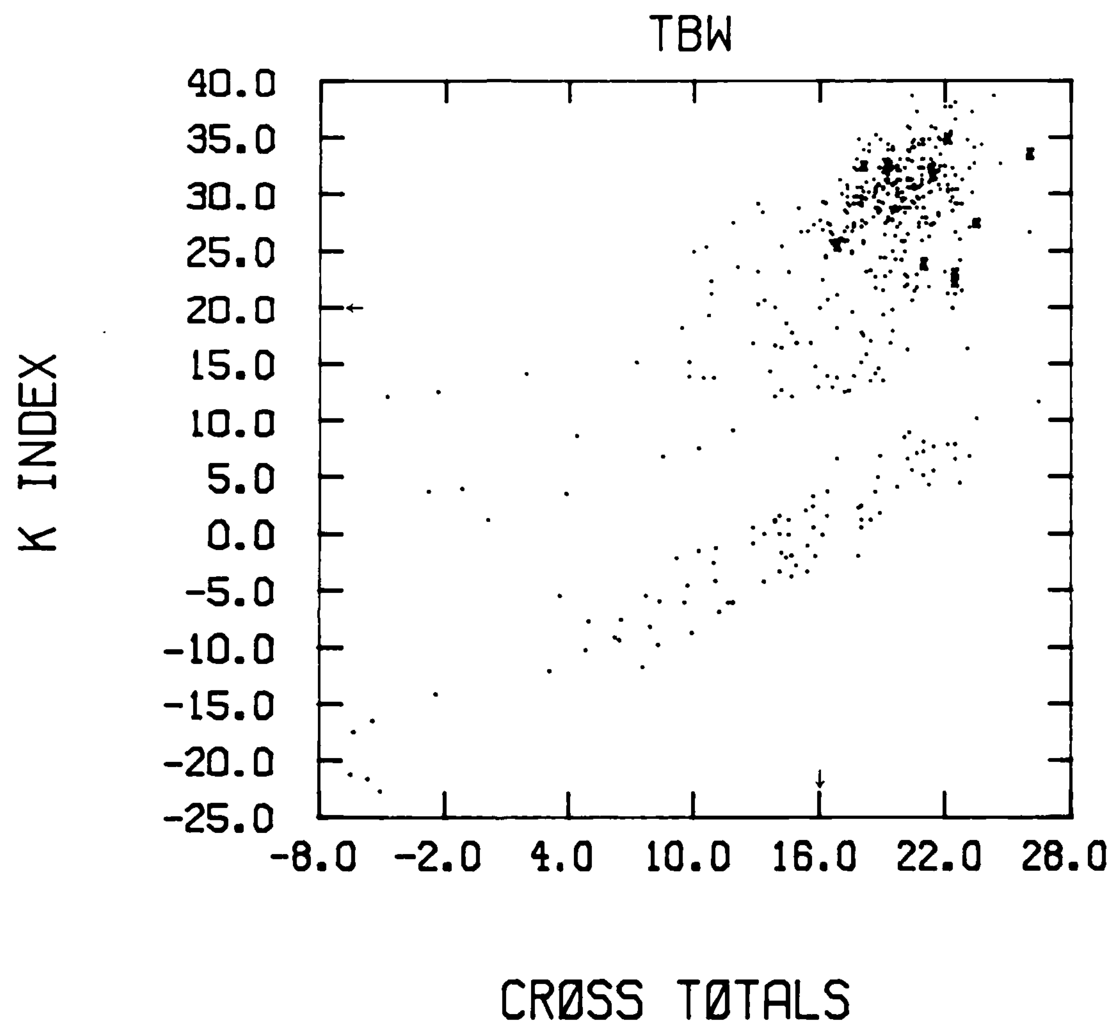

Fig. 5. Scatter plot of TBW CT versus KI. Both indices are expressed in units of °C. Same type of plot as presented in Fig. 2.

development over areas like Florida. All of the severe weather days had values greater than 23 at TBW and PBI (Fig. 6). Although Fig. 6 shows that this criterion was satisfied for most days within the period of study, the vertical totals index was included in the model to provide additional discretionary separation between days with and without reports of severe thunderstorm winds.

A Delta Theta-E index was used for the purpose of looking at potential instability present within the atmosphere, and to see if there was any relationship between the index and the occurrence of severe thunderstorm winds. On almost every day, Theta-E, or equivalent potential temperature, decreases with height through the middle troposphere over Florida.

The Johnson lag index (Johnson, 1982) was developed to provide a short-term forecast, or indication, of severe thunderstorms using temperature and equivalent potential temperature values at pressure levels between 900 and 500 mb, some of which are non-mandatory levels. For this study, the index was modified to incorporate upper-air data at mandatory levels which are consistently reported and available to forecasters.

Figs. 7 and 8 illustrate the range of values for both indices at PBI and TBW throughout the period of study. Although critical values have not been previously established for either index, it follows from their respective equations in Table 1 that negative values are more indicative of an unstable environment in which thunderstorm activity would occur. As seen in Figs. 7 and 8, almost all of the days within the period of study have negative values at TBW and PBI for both

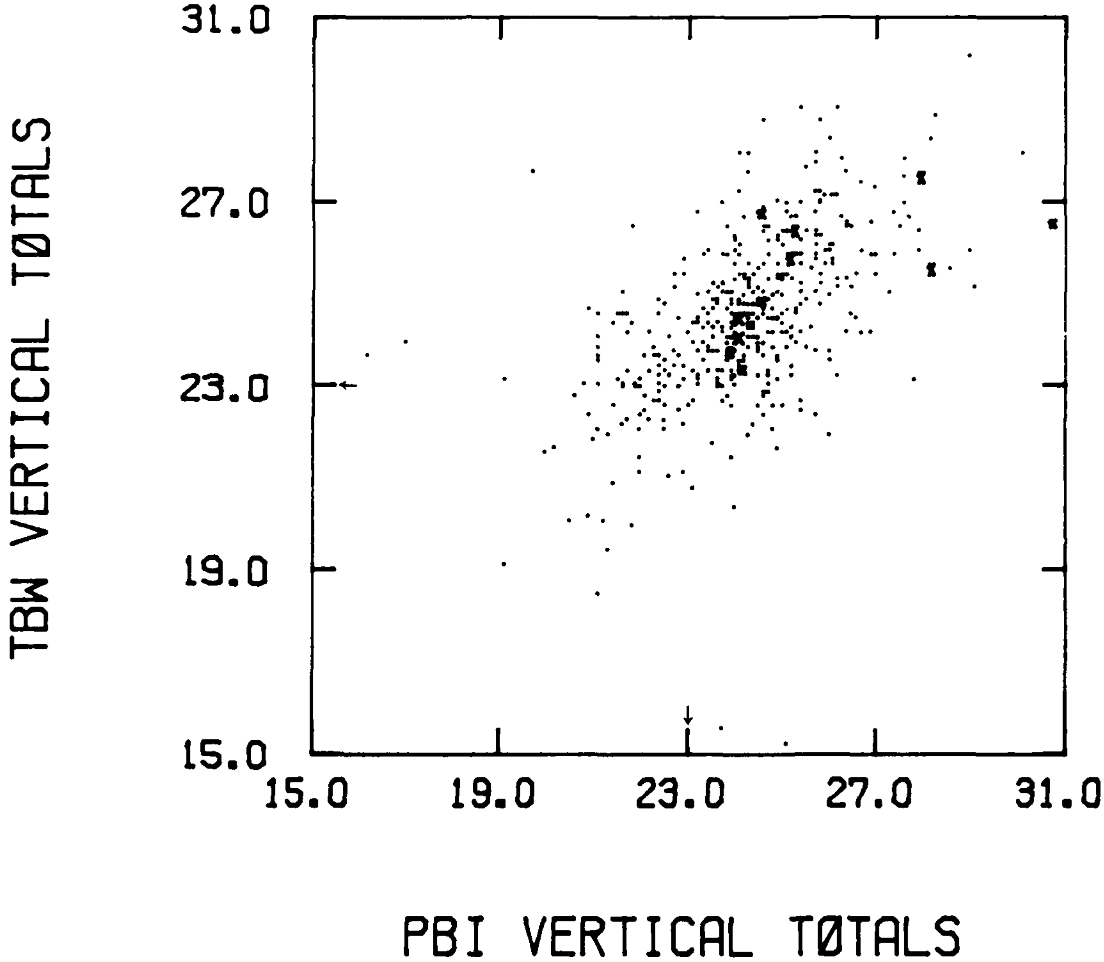

Fig. 6. Scatter plot of TBW versus PBI VT (^{o}C). Same type of plot as presented in Fig. 2.

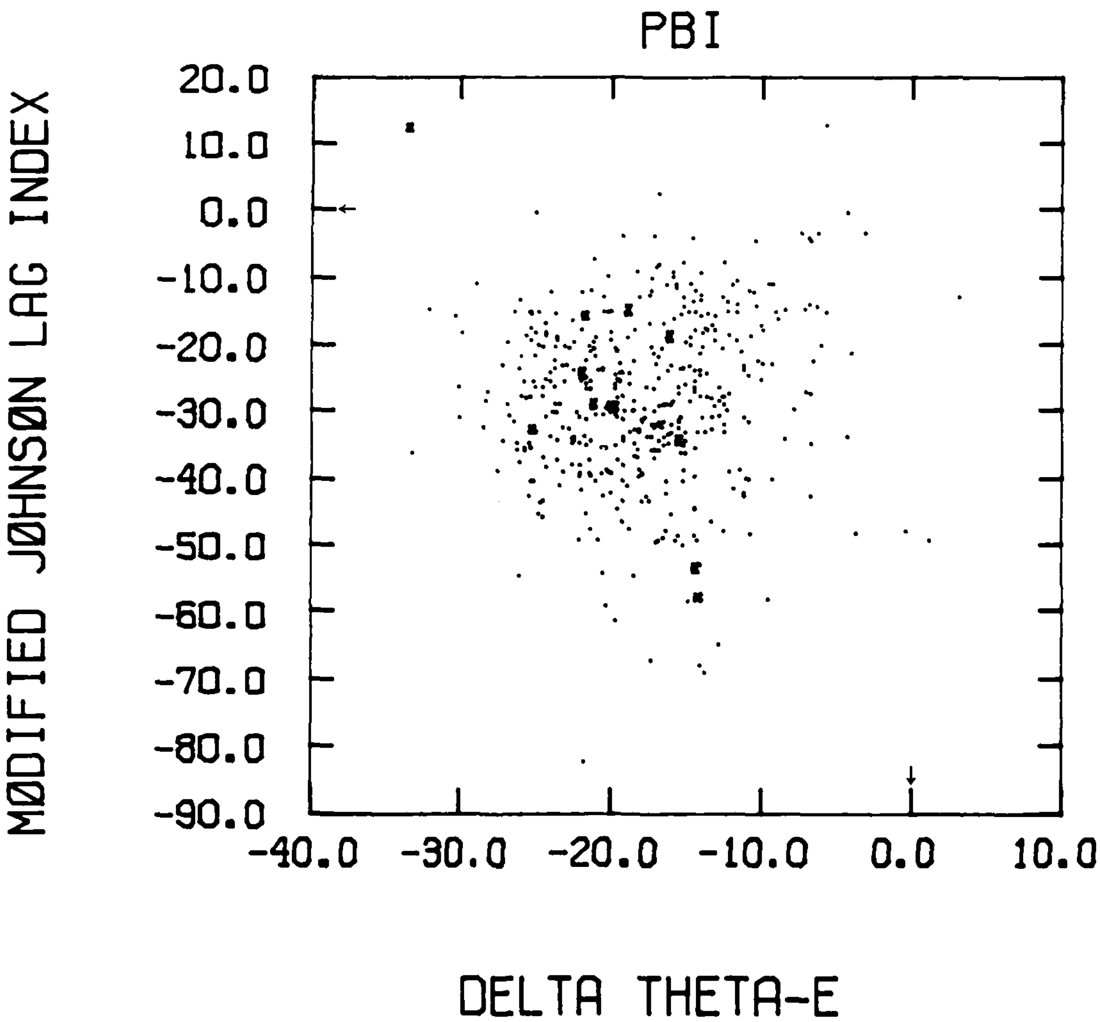

Fig. 7. Scatter plot of PBI $\Delta\theta_e$ versus MJLI. Both indices are expressed in units of ^oC. Same type of plot as presented in Fig. 2.

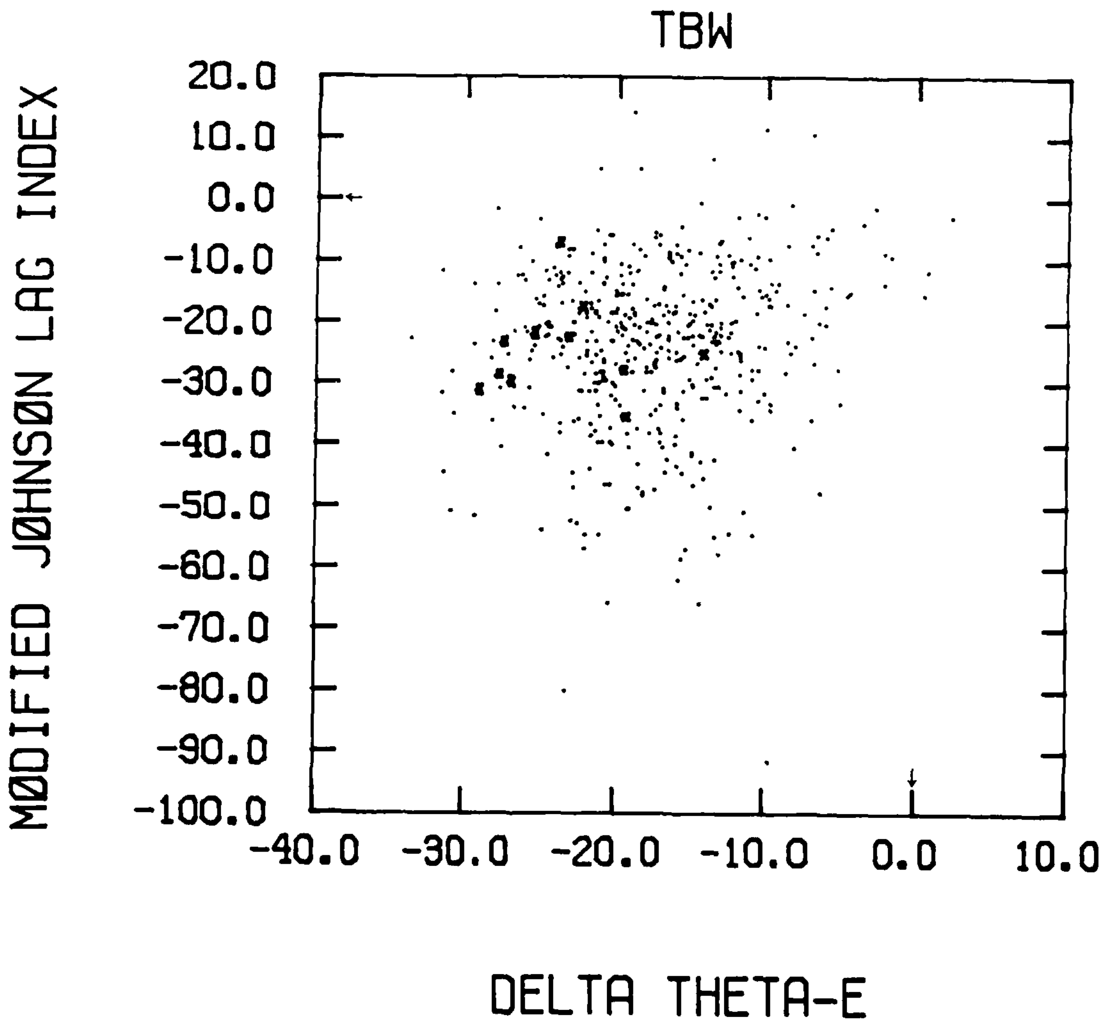

Fig. 8. Scatter plot of TBW $\Delta\Theta_e$ versus MJLI. Both indices are expressed in units of ^{o}C. Same type of plot as presented in Fig. 2.

indices. One severe thunderstorm wind event, though, has a positive modified Johnson lag index at PBI. Any distinction between severe thunderstorm wind events and other days is not possible, since the respective values for each severe date encompass a large range of values relative to the other days. Although all the Delta Theta-E index values on severe dates are less than or equal to -14, it was later determined that this index did not provide any more distinction between severe and non-severe dates than was already provided by other factors in the model.

Frequently, the stability indices described above are used to indicate the potential for severe thunderstorm activity. Once satisfying the critical criterion established for thunderstorm development, the magnitude of the indices are often related to the severity of the anticipated thunderstorms. Over Florida, critical values of some of the indices may be satisfied prior to the development of thunderstorm activity, but the magnitude of the indices is not often indicative of the intensity or severity of the thunderstorms. For example, consider three different dates - 5 June, 20 June, and 21 June of 1977. On 5 June, a tornado was reported in Polk County, east of TBW, causing between \$500 and \$5,000 of damage. On 20 June, a severe thunderstorm, assumed to be non-tornadic, caused over \$50,000 of damage in Polk County. On 21 June, there were no reports of any severe weather from Polk County, or any other neighboring county. Only one other day in June of 1977 had a report of severe thunderstorms over Polk County. Stability indices were calculated using upper air data from TBW, which is the closest station to Polk County, and from PBI,

since the PBI sounding may also be representative of the upstream environment in the predominant case of southeasterly flow over the peninsula. The stability indices, shown in Table 2, tend to show a trend opposite to that which would be expected from traditional studies of stability indices. Although only a few of the stability indices presented in Table 2 have been shown to be significant enough to include in a model indicative of non-tornadic severe thunderstorm winds, all of the stability indices are presented for comparison. Lower values of the LI, SSI, MJLI, and $\Delta\theta_e$, and higher values of the CT, VT, and KI are usually indicative of a more unstable environment, while relatively greater magnitudes are often related to greater severity of anticipated thunderstorms. The relative magnitudes of the stability indices at TBW indicate that 21 June 1977 was the most unstable day, while the indices from PBI indicate that the atmosphere was most unstable on 20 June 1977. The stability indices from both stations indicate the presence of a relatively stable environment on a day in which a tornado was reported. It is evident from the indices presented in Table 2 that the pre-convective environmental conditions associated with non-tornadic storms, as represented by stability indices, can be quite different from the conditions associated with tornadic thunderstorms over Florida. Notice that if the intensity of the storm were to be judged by a dollar estimate of the damage, the non-tornadic storm would be more severe, which makes the study of these storms even more important. Most importantly, one should realize that the point values of these stability indices cannot be used alone to forecast intensity or location of severe thunderstorms. It must also

Table 2. Examples of stability index values for individual days with and without reports of severe weather. Each entry has a value from PBI and TBW, respectively, separated by a slash. All values are ^{o}C. More unstable conditions are indicated by more negative values of the LI, SSI, MJLI, and $\Delta\theta_e$, and more positive values of the CT, VT, and KI.

Date	6/5/77	6/20/77	6/21/77
Event	Tornado	Svr Tstm	no reports
LI	-2/-1	-4/-4	-3/-6
SSI	2/4	0/4	2/2
CT	20/17	22/17	18/19
VT	22/24	25/24	27/25
KI	29/31	31/21	27/31
MJLI	-18/-14	-20/-36	-16/-37
$\Delta\theta_e$	-25/-9	-15/-22	-16/-20

be realized that we are comparing objective indices with subjective reports of severe thunderstorms.

b. Equivalent Potential Temperature (θ_e)

Equivalent potential temperature represents the temperature that an air parcel would have if lifted pseudo-adiabatically from its Lifting Condensation Level (LCL), the level at which a parcel of moist air becomes saturated after being lifted adiabatically, to a height where all moisture was condensed out, then descended adiabatically to the 1000 mb level (Holton, 1979). Bolton (1980) presented a computational procedure appropriate for calculating equivalent potential temperature in a tropical environment. This procedure was tested and used for all calculations of θ_e.

Values and distributions of equivalent potential temperature were analyzed to determine if any correlation existed between low values of equivalent potential temperature and occurrences of severe thunderstorm winds. Θ_e was initially evaluated throughout the lower troposphere, using the standard upper-air data reporting levels of 850, 700, and 500 mb. Considerable fluctuations in moisture, and temperature at 850 and 700 mb resulted in large variations of equivalent potential temperature among the days studied. In many instances, the equivalent potential temperature at 850 mb showed a diurnal fluctuation, perhaps indicative of the extensive amount of mixing occurring in the lower troposphere each day (Fig. 9). 24 days of the 30 days represented in Fig. 9 showed a drop in equivalent potential temperature at 850 mb from 0000 to 1200 GMT. Fig. 9 alone suggests that the low-level thermodynamic conditions change considerably throughout the day over Florida.

The minimum equivalent potential temperature (MINEPT) variable that was developed represents a combination of features which were present in the pre-convective environment of the severe weather dates. The MINEPT was chosen as the minimum equivalent potential temperature value within a layer of winds, between 700 and 450 mb, which backed with height, and whose directions were from the northwest quadrant (270°-360°). The MINEPT value for either TBW or PBI was found to be less than 326.0 K on severe dates, as shown in Fig. 10. The cluster of points in the lower right part of the graph represent the surface Θ_e, used in the event that the backing wind criteria were not met. Inclusion of the PBI lifted index in Fig. 10 also demonstrates its

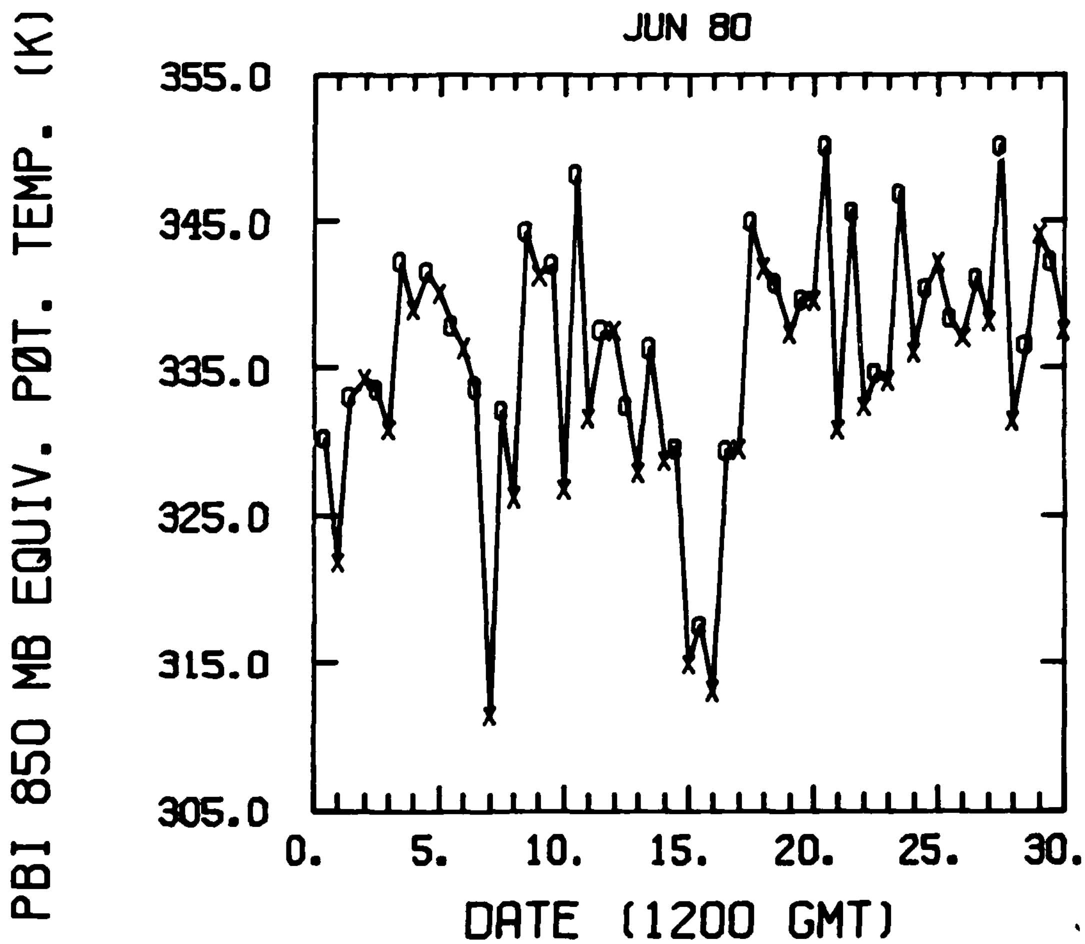

Fig. 9. Plot of equivalent potential temperature (K) at 850 mb from PBI every 12 h. Plot begins at 1/0000 GMT and ends at 30/1200 GMT. Points at 0000 GMT are represented by an "O" and points at 1200 GMT are represented by an "X". Note the frequent decrease in equivalent potential temperature from 0000 GMT to 1200 GMT.

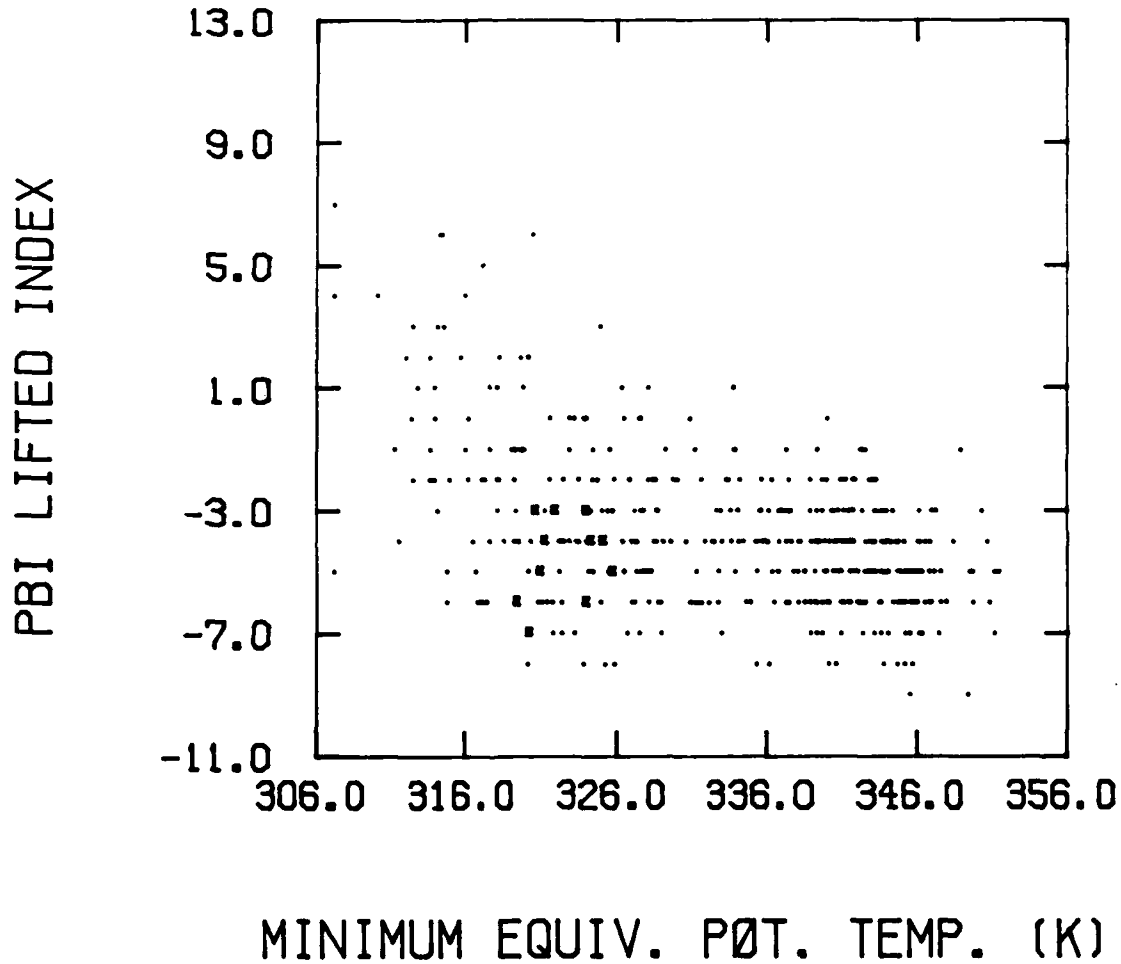

Fig. 10. Scatter plot of MINEPT (K) versus PBI LI (^{o}C). Same type of plot as presented in Fig. 2. The MINEPT represents the minimum Θ_e value within a layer of backing winds from the northwest quadrant between 700 and 450 mb from PBI or TBW. Surface Θ_e was plotted if the backing wind criteria were not satisfied.

importance in distinguishing severe days from non-severe days. In most cases, the TBW MINEPT was less than the PBI MINEPT. Northwesterly winds suggest an advection of lower equivalent potential temperature into the mid-levels of southern Florida, and the concurrent presence of backing winds implies cold air advection within that mid-tropospheric layer, helping to maintain the already dry, potentially cool air typically present in the pre-convective environment of thunderstorms with damaging surface winds. Caracena and Maier (1979) found an advection of lower equivalent potential temperature into South Florida in their 1200 GMT 500 mb analysis, prior to the occurrence of a microburst.

c. Destabilization Through Differential Thermal Advection

Veering (clockwise turning) or backing (counterclockwise turning) of the wind with height, within a layer, can be used to determine thermal advection within that layer. Using upper air wind observations, veering and backing of the wind was analyzed throughout the lower and middle troposphere to see if the days with reports of severe thunderstorm winds demonstrated any indications of a destabilization of the environment. The thermal wind relationship (Holton, 1979) was used to calculate thermal advection within a layer of the atmosphere. Temperature change within a layer can be represented by

$$\frac{d(\delta z)}{dt} = \frac{\partial(\delta z)}{\partial t} + \mathbf{V} \cdot \nabla(\delta z) + \omega \frac{\partial(\delta z)}{\partial p},$$

where the height thickness of the layer (δz) is proportional to the mean temperature of the layer. If diabatic changes of temperature are

negligible ($d(\delta z)/dt=0$), and vertical motion is negligible ($\omega=0$), the local rate of change of thickness, or temperature, is

$$\frac{\partial(\delta z)}{\partial t} = -\mathbf{V} \cdot \nabla(\delta z) = -V \cos \alpha \frac{d(\delta z)}{dn},$$

where α is the angle between the observed wind vector and $\nabla(\delta z)$. Since $-V \cos \alpha = -\mathbf{V}_n$, and

$$V_T = \frac{g}{f} \frac{d(\delta z)}{dn},$$

it follows that $\frac{\partial(\delta z)}{\partial t} = \frac{-f}{g} \mathbf{V}_n \mathbf{V}_T$,

where $\mathbf{V}_T$ is the thermal wind in the layer, and $\mathbf{V}_n$ is the component of the wind (upper or lower level) normal to the thermal wind. In trying to avoid any violation of the geostrophic wind assumption used in deriving the thermal wind, only winds with speeds of 2 m s^{-1} or greater were used in any calculations.

Fig. 11 contains hodographs from TBW and PBI for two severe thunderstorm wind events. Both cases show an inconsistent veering and backing of the wind. Thermal advection can be evaluated by dividing the 900-500 mb layer into two layers. The 900-700 mb layer is represented by points 3 and 7, respectively. The 700-500 mb layer is represented by points 7 and 11, respectively. The thermal wind is represented by the vector from points 3 to 7, and 7 to 11, for the lower and upper layers, respectively. The amount of thermal advection is proportional to the area of the triangle formed by the same points. On 20 June 1980, a more significant amount of warm-air advection is implied in the lower layer than in the upper layer of PBI, therefore resulting in a destabilization of the environment. Very little thermal

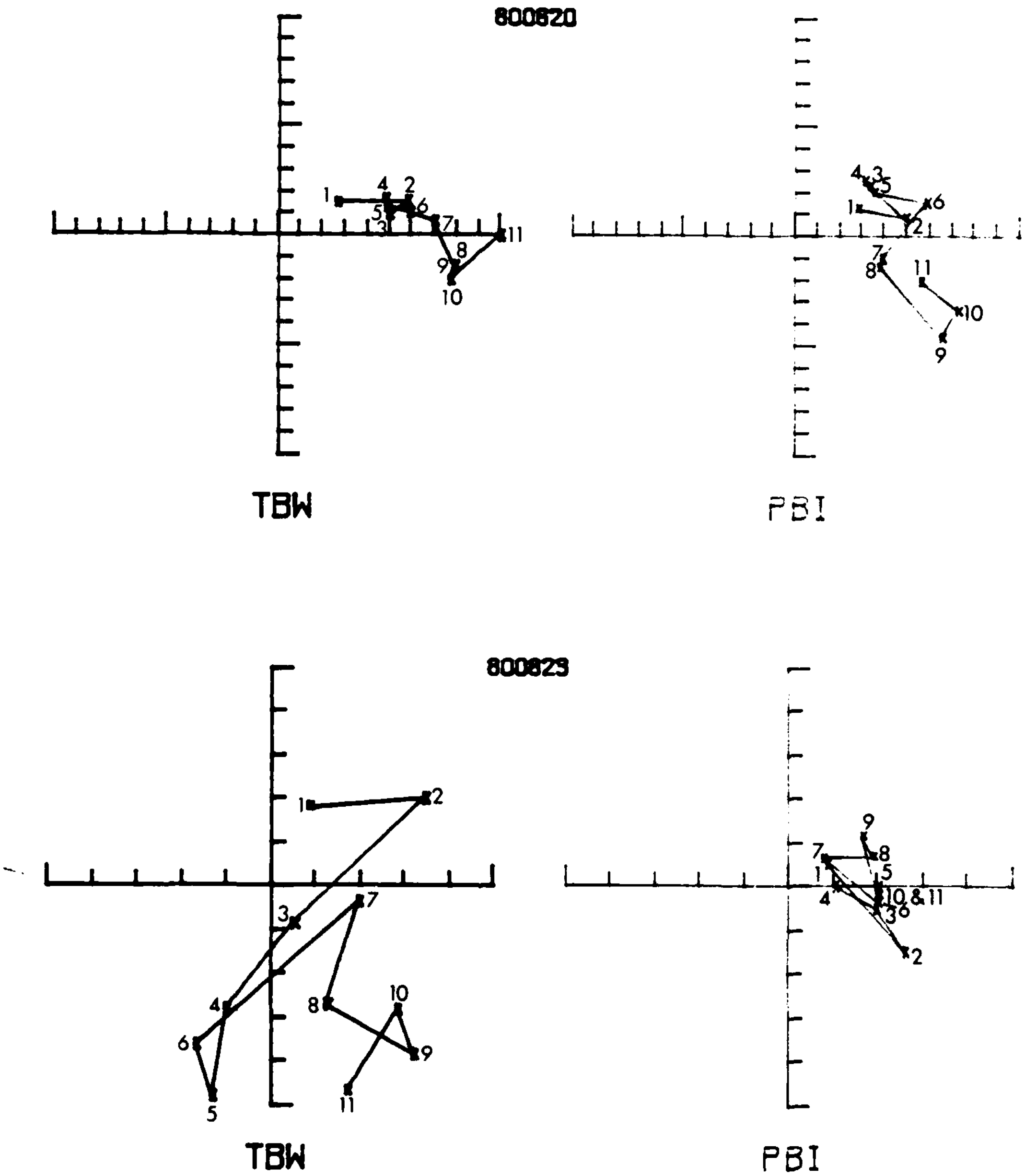

Fig. 11. Hodographs plotted every 50 mb from 1000 to 500 mb for 20 June and 23 August 1980. Each hodograph point is labelled by ascending numbers and each axis is marked in intervals of 1.0 m s^{-1}. Both dates represent severe thunderstorm wind events.

advection is implied by the TBW hodograph. On 23 August 1980 at PBI, cold air advection is implied in the lower layer, while warm air advection is implied in the upper layer. This results in a stabilization of the environment, although obviously not enough to prevent severe thunderstorms from developing. Stabilization of the environment is also implied by the TBW hodograph. Evaluation of hodographs and upper-air data for all days with reports of severe thunderstorm winds revealed no consistent indications of significant stability change, except in conjunction with levels of minimum equivalent potential temperature in the mid-levels of the troposphere.

An example of variations in atmospheric stability is seen by a time profile plot of the lifted index in Fig. 12. During the time period covered by the graph, 20 June and 26 June were days with reports of severe thunderstorm winds. The lifted index values on these dates were identical, and showed absolutely no change prior to the occurrence of severe thunderstorm winds. The graph also shows a general trend of increasing instability throughout the month going into the middle of the thunderstorm season, although the atmosphere is almost always unstable over Florida at this time.

d. Evaluation of Directional Wind Shear and Mean Wind Direction

As indicated by Pielke (1974) and Atkinson (1981), thunderstorms in tropical areas, such as Florida, often develop in an atmosphere marked by very little directional wind shear. Hodographs, plotted for each day with a report of severe thunderstorm winds, show that the environmental winds are very dissimilar from the winds characteristic of severe thunderstorms over the midwest. Fig. 11 represents two

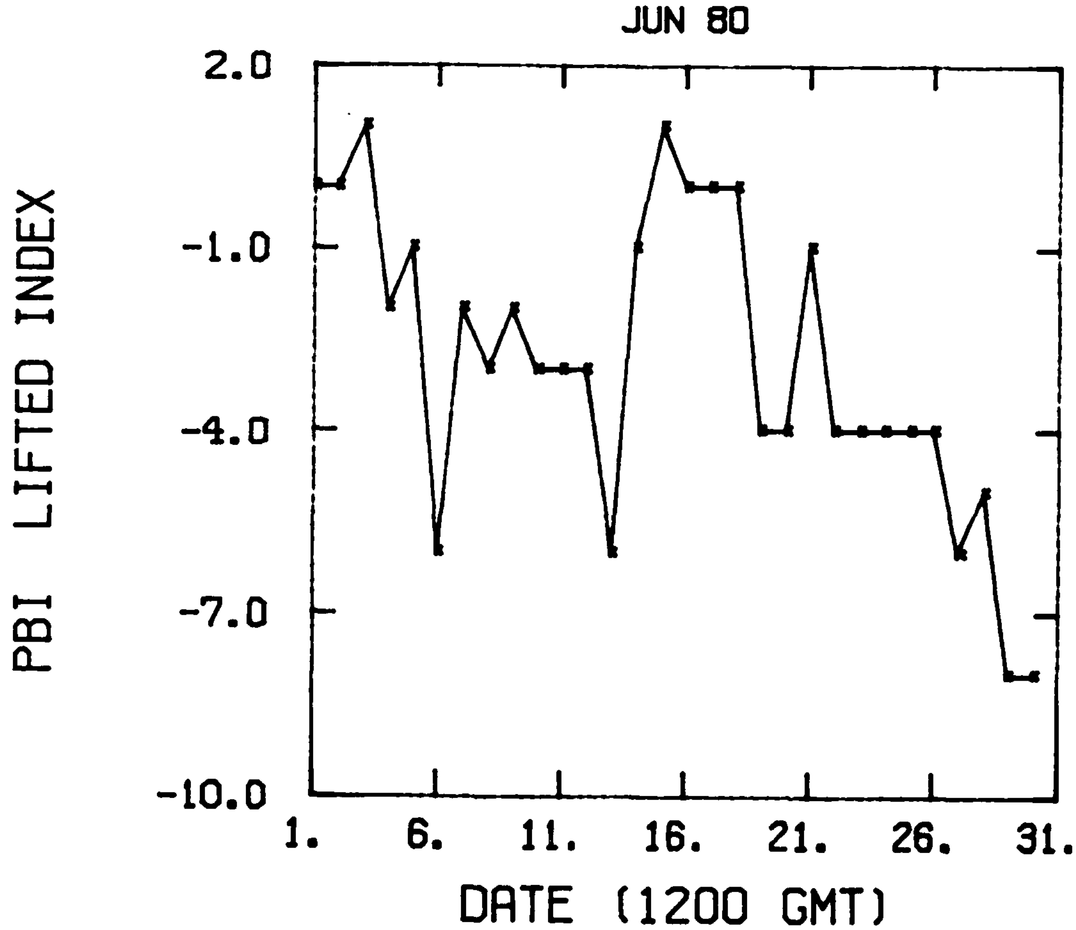

Fig. 12. Daily plot of the 1200 GMT LI at PBI during June 1980. Significant changes in the lifted index did not occur on severe weather days, as indicated by values on the 20th and 26th. A general trend of increasing instability is also observed to exist throughout the month.

examples of hodographs on days with reports of severe thunderstorm winds. Directional wind shear was evaluated for each day using the minimum difference between either the 950 or 900 mb wind, represented by points 2 and 3 on the hodographs, and either the 550 or 500 mb wind, represented by points 10 and 11. These levels were consistently available in the upper-air data, and allowed for some variability between the lower and middle level wind direction used, in case one of the winds was reported as calm. Some points on the graph have directional wind shears greater than 180^{o}, since differences in wind direction were calculated in a strict mathematical sense, and did not account for veering or backing of the wind through the 360^{o} compass point.

In the analysis of directional wind shear between the lower and upper levels of the troposphere, it was found that a directional shear of less than 45^{o} existed at TBW and PBI on every severe weather day (Fig. 13), with the exception of 23 June 1976, in which case severe weather wasn't reported until after 0000 GMT. All other reports of severe thunderstorm winds occurred before 0000 GMT. On 23 June 1976, only the directional wind shear at TBW was greater than 45^{o}. Fig. 13 illustrates the limited amount of directional wind shear present on most days throughout the summer, and the tendency of those days with reports of severe thunderstorm winds to exhibit an even smaller amount of directional wind shear.

A mean wind direction was calculated based on the lower and upper level wind directions used to evaluate the directional wind shear. It was found that the mean wind directions at TBW and PBI were from a

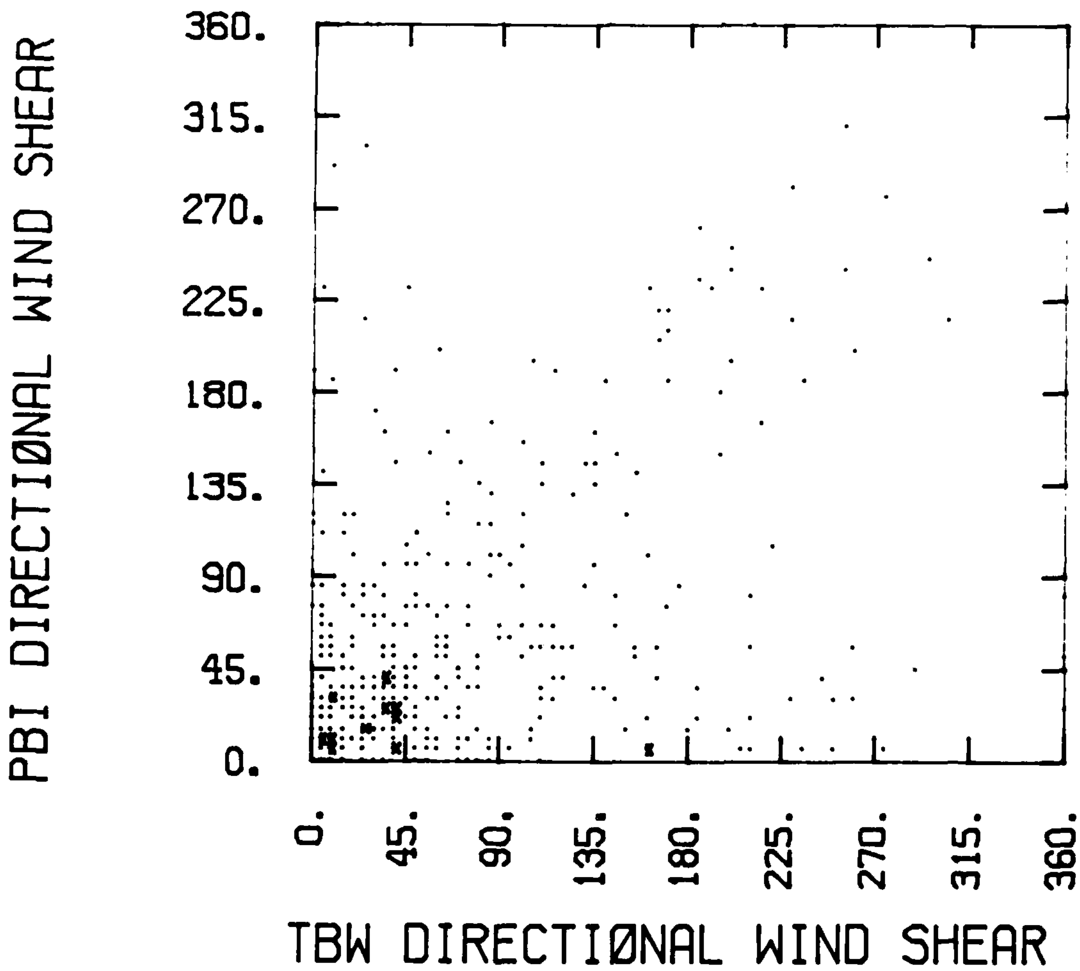

Fig. 13. Scatter plot of TBW versus PBI directional wind shear in units of degrees. Same type of plot as presented in Fig. 2.

directional range of 225^{o}-360^{o} (SW-N) (Fig. 14), with the exception of the 23 June 1976 case. On this day, low-level winds were from the southeast, while a 500 mb convergence zone over the middle of the state at 1200 GMT was observed to push off the east coast of the peninsula within 12 h succeeded by northwesterly winds. Fig. 14 shows the grouping of days with reports of severe thunderstorm winds in the upper right corner of the graph, representing a consistent northwesterly flow within the troposphere. With the exception of one case, this factor appears to be a very distinguishing feature among severe thunderstorm wind events, since many other days are characterized by other mean wind directions. The figure also indicates that the mean wind directions for TBW and PBI are within 90^{o} of each other on almost every day within the period of study. A mean wind direction from a westerly direction indicates a significant change from the southeasterly flow which is common over South Florida during the wet season (Pielke, 1974). When the synoptic flow is from the west, sea-breeze convergence zones, established along both coasts, usually during the late morning, may merge along the east coast of the peninsula in the afternoon. The merging of these two primary convergence zones, accompanied by well-developed thunderstorm activity, provide the potential for severe thunderstorm activity to rapidly develop. It is also likely that any sea-breeze circulation and convergence developing along the east coast would be stronger than normal, since westerly flow in the lower and upper levels of the troposphere would enhance convergence zones, in addition to countering their penetration inland.

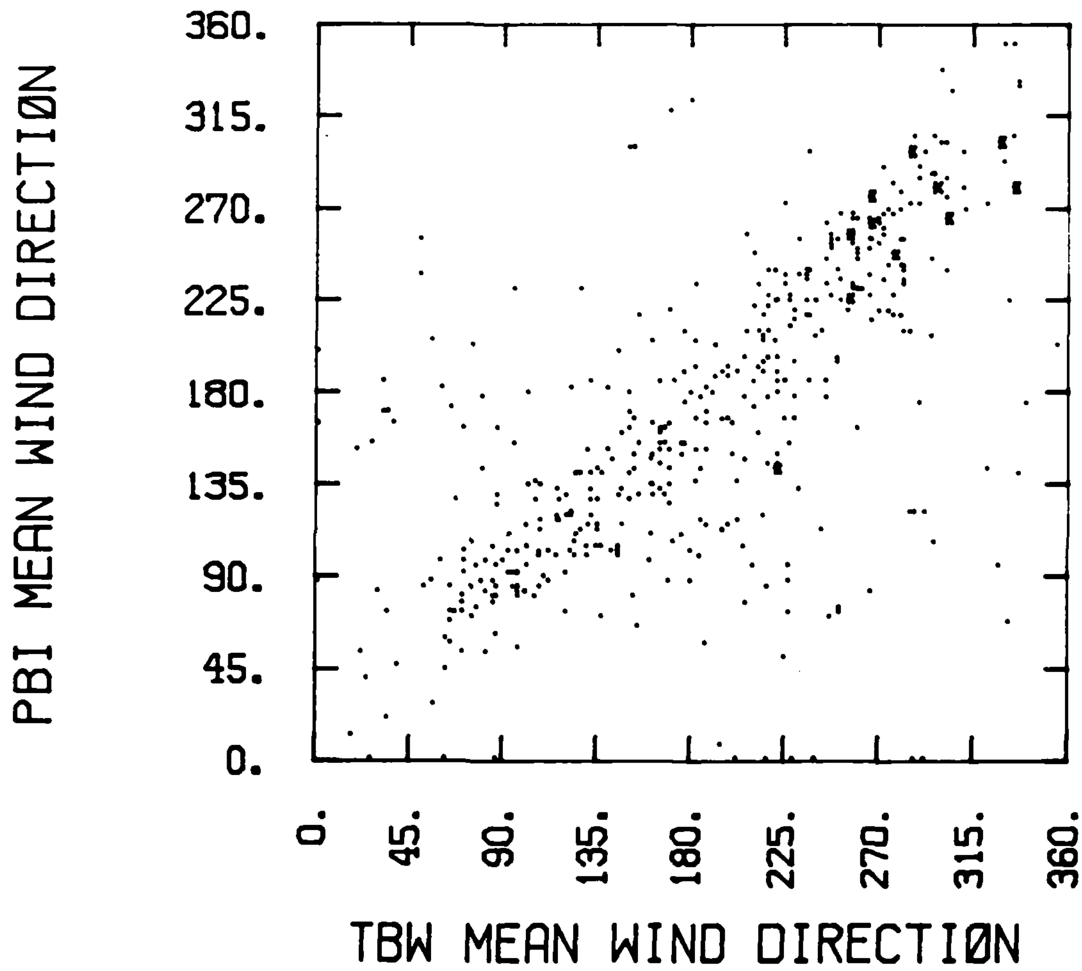

Fig. 14. Scatter plot of TBW versus PBI mean wind direction in units of degrees. Same type of plot as presented in Fig. 2.

e. Adiabatic Sub-Cloud Layer

Strong thunderstorm downdrafts result from a descent of evaporatively cooled air which is initially much cooler than the surrounding air. This is especially important at the base of a cloud where a sub-cloud layer of air is heated by vertical mixing of air from the hot surface of the earth. If the sub-cloud layer is assumed to have an adiabatic lapse rate, prior to the occurrence of rainfall, then the descent of the downdraft will continue throughout the depth of the sub-cloud layer until it reaches the ground, since the moist, cooler air will descend pseudo-adiabatically, remaining consistently colder than the environmental air. The descent of this cool, moist air marks the edge of the outflow as the air spreads out along the ground. The depth and characteristics of the sub-cloud layer can obviously be very important to the resulting strength of the thunderstorm outflow.

Using the 1200 GMT sounding, the depth of an adiabatic sub-cloud layer was calculated using the intersection of the 303 K (30^{o} C) adiabat (equating to a surface temperature of about 31^{o} C, or 88^{o} F) with the actual sounding as a representative cloud base height. This is a very simple approach to a complex process, and assumes that only the area within the depth of the calculated adiabatic layer will be significantly modified.

The depth of the adiabatic sub-cloud layer, in millibars, was calculated for each day. The results of the calculations are represented in Fig. 15. A wide range of values on days with reports of severe thunderstorm winds, indicated by X's, is found in the graph. This variable does not show any means of distinguishing severe

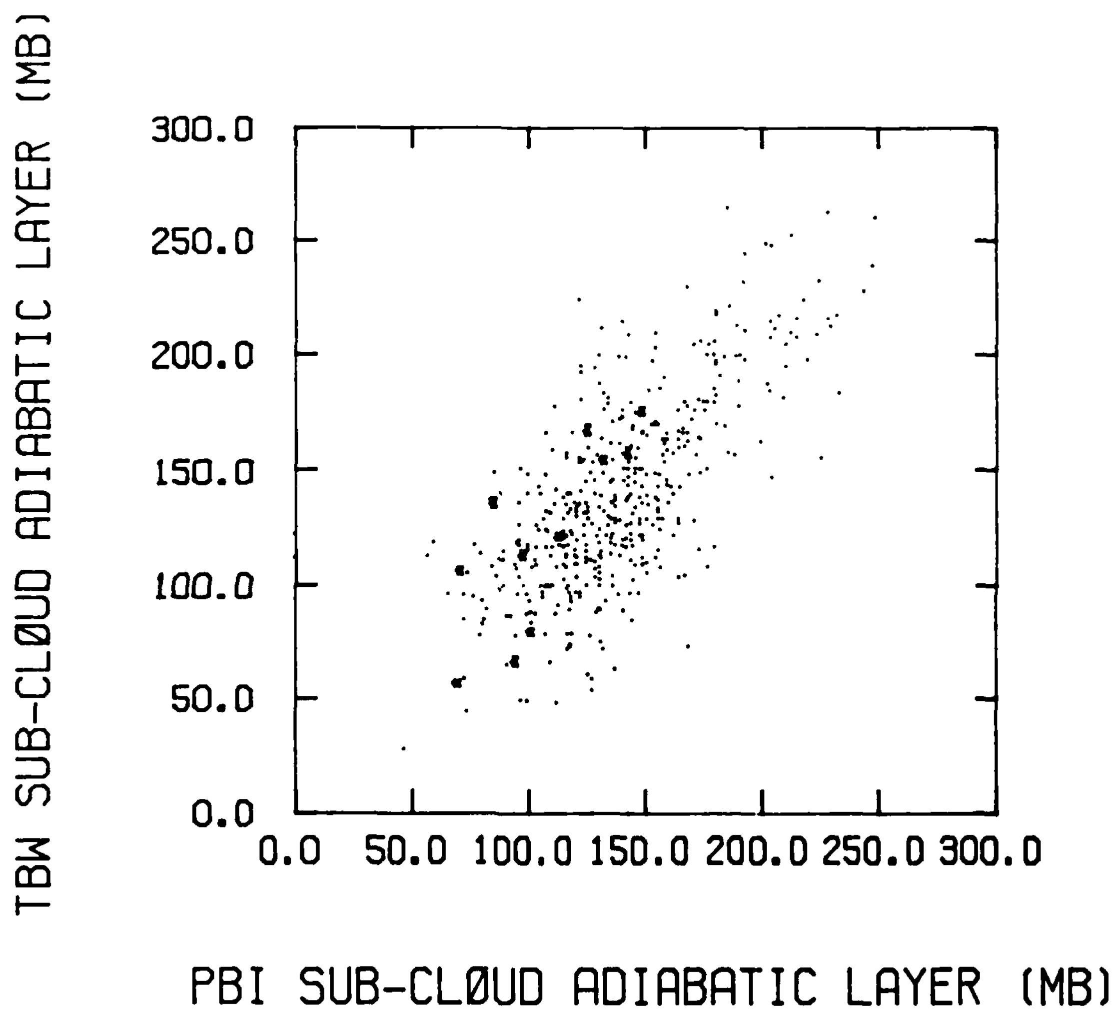

Fig. 15. Scatter plot of TBW versus PBI depth of adiabatic sub-cloud layer expressed in millibars. Same type of plot as presented in Fig. 2.

thunderstorm wind events from other days.

f. Surface Moisture Convergence

Hourly surface data were obtained to evaluate the hourly patterns and amount of surface moisture convergence present over the southern Florida peninsula. Due to the distribution of standard reporting stations over South Florida, it is not possible to routinely measure surface moisture convergence at the convective scale. Therefore, peninsula-scale surface moisture convergence was studied to see if there were any pre-convective patterns indicative of severe thunderstorm wind events over Southeast Florida. Relatively higher values of surface moisture convergence were anticipated prior to the occurrence of severe thunderstorm winds, since more intense storms have been reported to be associated with greater amounts of moisture convergence (Charba, 1975; Ostby, 1975).

Assuming zero vertical flux, the integrated rate of change of moisture within a specified boundary can be represented by

$$-\iint \nabla \cdot q\mathbf{V}\, dA = -\int q \cdot \mathbf{V}_n\, ds = -\Sigma\, \overline{q \cdot \mathbf{V}_n}\, \Delta s\ ,$$

where q is the specific humidity, approximated by the mixing ratio, $\mathbf{V}_n$ is the component of the wind normal to a line bounded by two stations, and Δs is the distance between two stations. A computer program was written to compute the distance between two points, given the latitude and longitude of each point, by using navigational mathematics (Bradley, 1942). The total surface moisture change was divided by the applicable area enclosed by the surface network to obtain an area-averaged value of moisture change, or moisture convergence, in units of s^{-1}.

Surface moisture convergence values were examined for unusually high values or unique trends on days of severe thunderstorm wind events. Figs. 16 through 19 show plots of surface moisture convergence at 3 h intervals observed on individual days, along with radar summaries. Values of surface moisture convergence are comparable to results from other researchers (Negri and VonderHaar, 1980), although the amount of moisture convergence present is indicative of significant convergence and suggests a likelihood of intense convective activity almost everyday. Fig. 16 represents a day with little or no convection occurring over southern Florida. There is convergence, but only one isolated cell develops. Figs. 17 and 18 show moisture convergence patterns associated with the development of severe thunderstorms over southeastern Florida. Severe thunderstorm winds were reported during the afternoon of 20 June 1980 (800620), and at 1830 GMT on 26 June 1980 (800626). The moisture convergence pattern, illustrated in Fig. 17, is very normal, exhibiting a diurnal trend between nighttime divergence and daytime convergence, due to the sea-breeze circulation. Values of moisture convergence during the afternoon are comparable to days with relatively little thunderstorm activity. In fact, the moisture convergence values on 16 and 20 June are almost identical with the exception of values at 1500 GMT. Fig. 18 shows that surface moisture convergence on 26 June did not increase until after the time that a severe thunderstorm was reported. Although the peak in moisture convergence on 26 June is significantly higher than the two previous cases, and the radar summary indicates heavy thunderstorm activity, no severe weather reports were received during or after 2100 GMT.

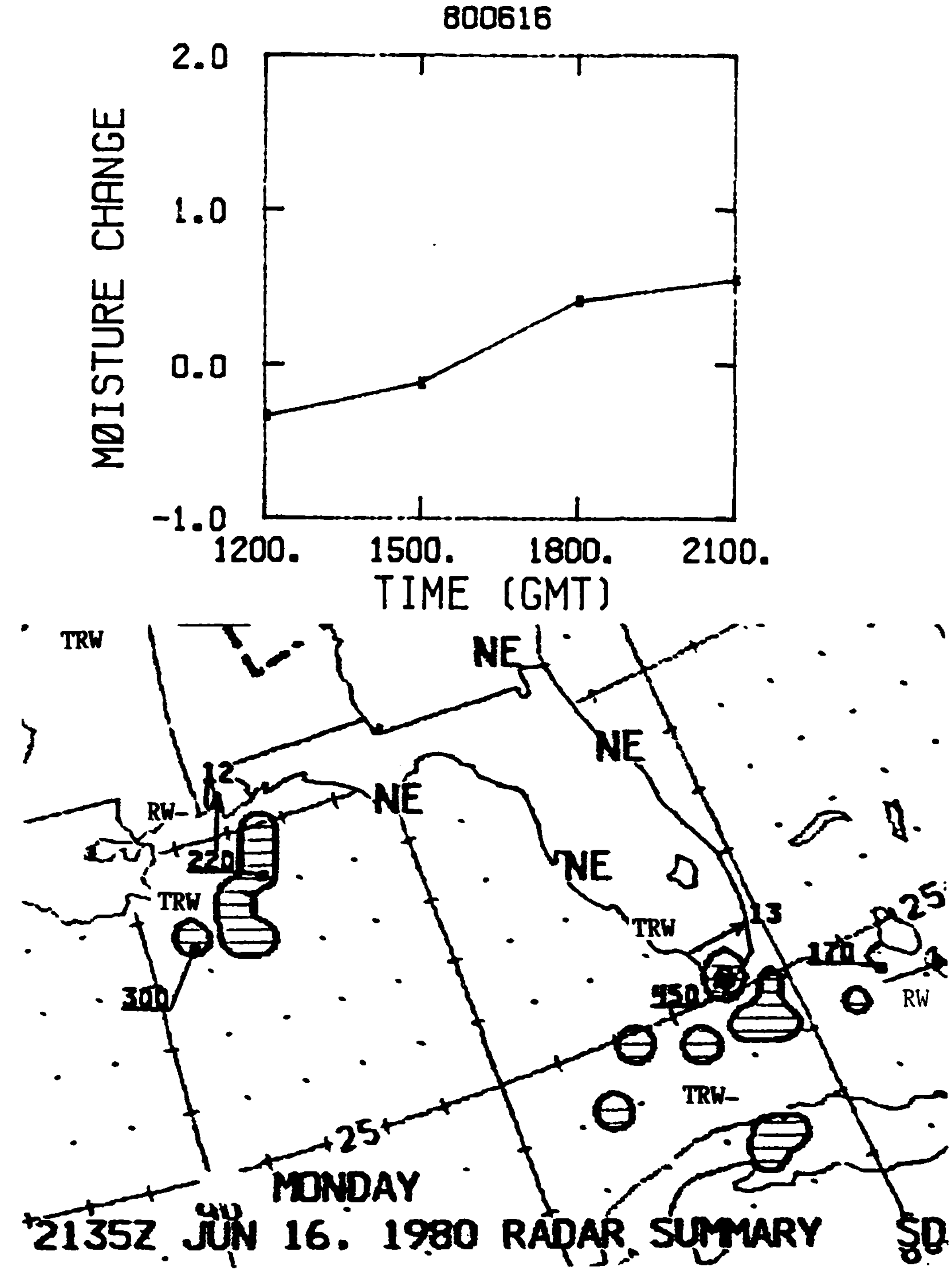

Fig. 16. Surface network moisture change (10^{-6} s^{-1}) plotted at 3 h intervals and an associated radar summary for 16 June 1980. Shading on radar summary indicates echo areas. Contours at echo intensities 1, 3, and 5; echo heights are in thousands of feet; cell movement given at end of arrows in knots; area and line movement given by pennant with full barb = 10 kt (U.S. Department of Commerce, 1981b).

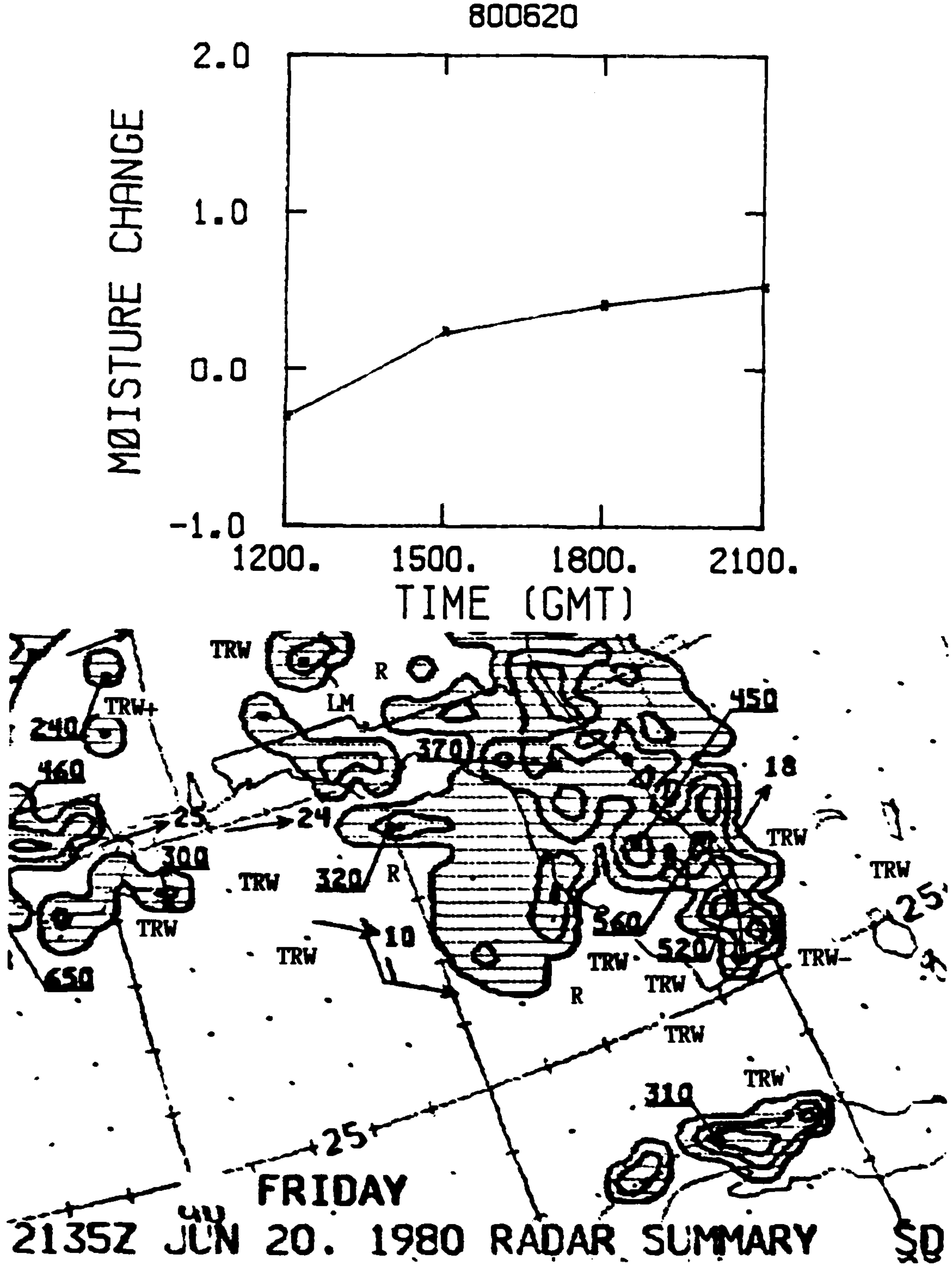

Fig. 17. Surface network moisture change (10^{-6} s^{-1}) plotted at 3 h intervals and an associated radar summary for 20 June 1980. Radar summary chart is described in Fig. 16.

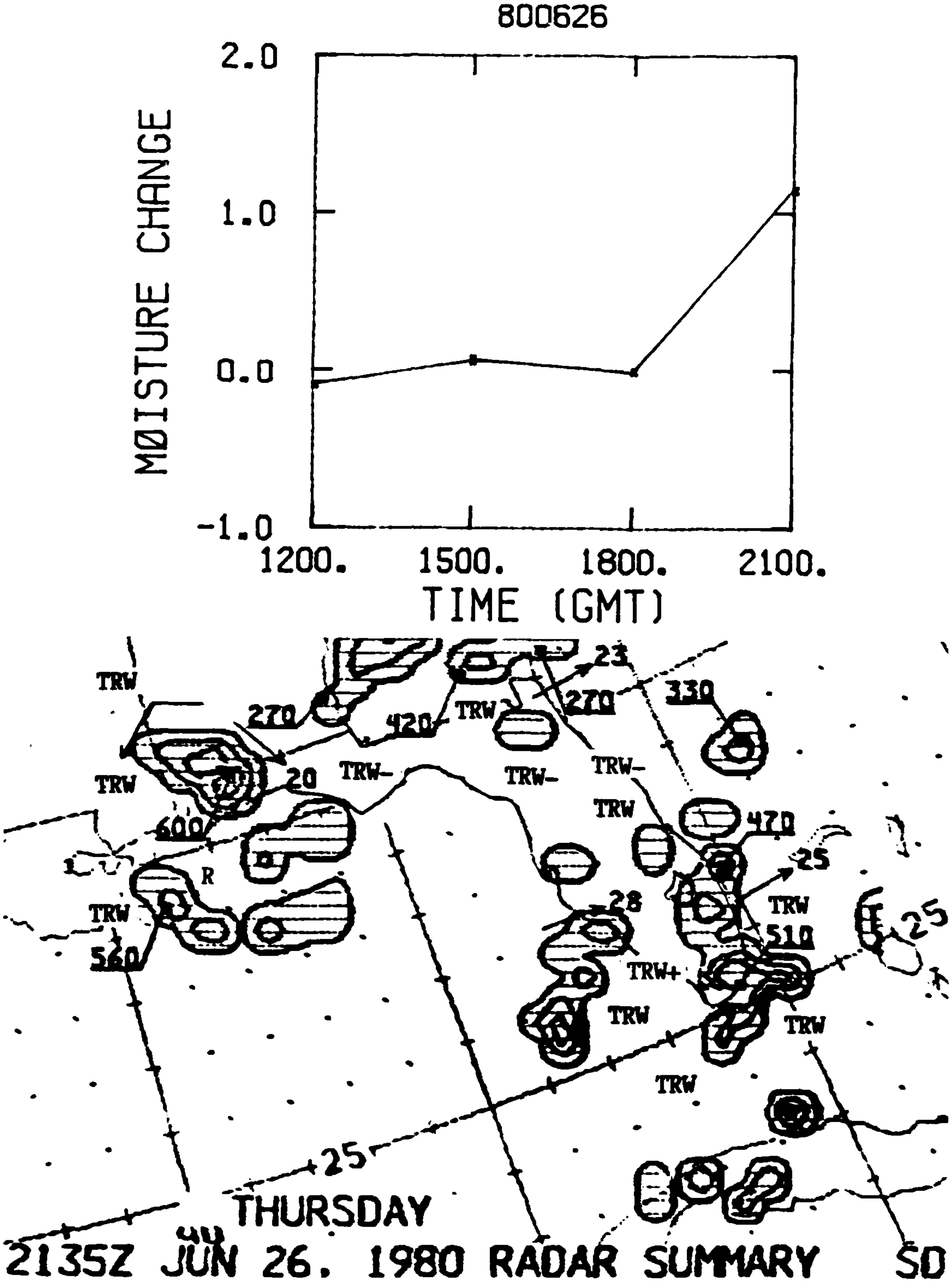

Fig. 18. Surface network moisture change (10^{-6} s^{-1}) plotted at 3 h intervals and an associated radar summary for 26 June 1980. Radar summary chart is described in Fig. 16.

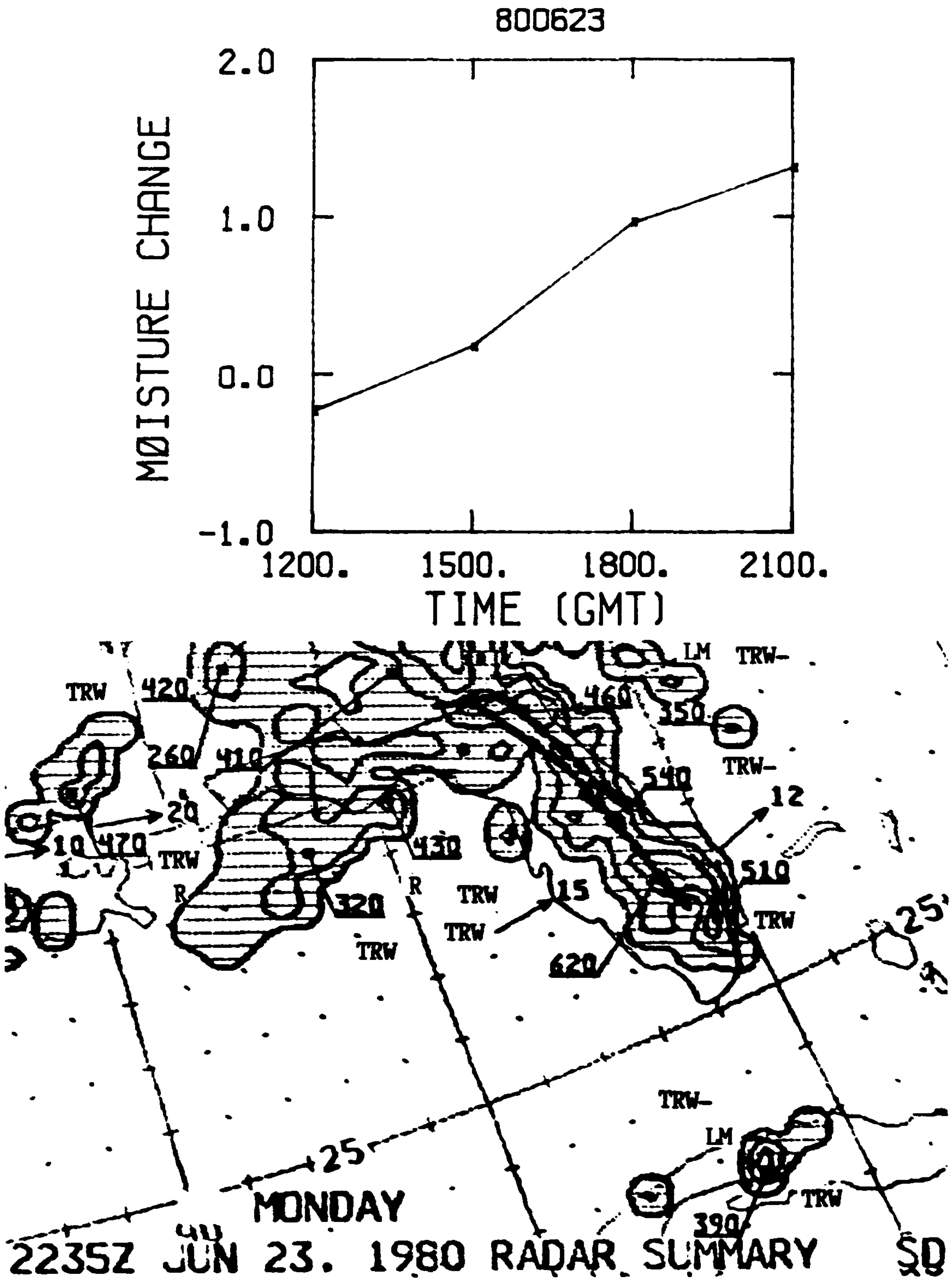

Fig. 19. Surface network moisture change (10^{-6} s^{-1}) plotted at 3 h intervals and an associated radar summary for 23 June 1980. Radar summary chart is described in Fig. 16.

Comparing surface moisture convergence among various days reveals little discernable difference that can be used to distinguish severe days from other days. Since the surface network encompassed a larger area than the three-county area used in this study, it is possible that severe thunderstorms outside the three-county area could exist within the surface network. The differences in scale between the area enclosed by the surface stations, and the area from which severe thunderstorm wind reports were taken makes any use of this factor in the model almost impossible.

Some of the difficulties encountered in comparing moisture convergence and other synoptic features among different days is illustrated by an extremely interesting situation on 23 June 1980 (Fig. 19). The moisture convergence is much greater than on days when severe thunderstorm winds were reported, and the radar summary is indicative of very intense thunderstorms with tops exceeding those observed on days with reports of severe thunderstorm winds over Southeast Florida. However, there were no reports of any severe weather over the three-county area, nor within the surface network. In fact, there were no reports of severe weather of any kind over the entire state that day. This lack of severe weather reports seems incredible and puzzling. If no storm reports exist on a scale much larger than the three-county area being studied, v h far greater indications of severe thunderstorms than may be normally indicated, it is quite likely that many severe weather events occur in Florida without being reported; it is not possible to estimate how many events are unreported. Obviously, Storm Data is recognized to be less than

100 % accurate (Doswell, 1985); it has been found here to provide a very unreliable means of verifying severe storm existence over Florida.

g. Establishing and Testing the Model

The establishment of a model involves choosing several factors representative of synoptic features which were present on every day with a report of severe thunderstorm winds over Southeast Florida during the 459 days of study. The factors included in the model rely on temperature, moisture, and wind profiles of the TBW and PBI upper-air soundings. The factors chosen and their critical values are listed in Table 3. Data from all of the upper-air stations identified in Fig. 1 were initially analyzed. It was determined, however, that PBI and TBW were the upper-air stations which provided the most consistent and applicable environmental indications of severe thunderstorm winds over Southeast Florida. Apart from the Palm Beach sounding, the Tampa sounding is important since it provides an indication of the atmosphere upstream of the area of interest. Low-level and upper-level wind directions indicate very little shear in the pre-convective environment and a mean wind direction generally from the northwest. This departure from the normal southeasterly flow is important in the development of intense thunderstorms along the southeast coastal area; the departure from the easterly trade wind flow of the tropics is indicative of a mid-latitude influence penetrating southeastward across the peninsula. The analysis of equivalent potential temperature throughout the middle troposphere in conjunction with backing winds with height from the northwest quadrant suggests that an area of dry, potentially cool air, moving southeastward across

Table 3. Factors and their critical values used in a model to indicate a potential for severe thunderstorm winds over Southeast Florida. All values are °C, unless otherwise indicated.

FACTOR		CRITICAL VALUE
TBW Lifted Index	PBI Lifted Index	$\leq$ -3.0
TBW Vertical Totals	PBI Vertical Totals	$\geq$ 23.0
TBW Directional Wind Shear (950/900 - 550/500 mb)	PBI Directional Wind Shear	< 45°
TBW Mean Wind Direction (950/900 - 550/500 mb)	PBI Mean Wind Direction	$\geq$ 225°
TBW Cross Totals		$\geq$ 16.0
TBW K Index		> 20.0
TBW or PBI Minimum Equivalent Potential Temperature (found within a layer of backing winds within the NW quadrant between 700 and 450 mb)		< 326.0 K

the peninsula, is likely contributing to the development of non-tornadic severe thunderstorms over Southeast Florida. Other indices in the model are helpful in indicating the atmospheric instability over southern Florida.

The final form of the model was tested over the 459 day period from 1976, 1977, and 1980. In order for a day to be selected by the model as having the potential for severe thunderstorm winds, all criteria had to be satisfied. Twelve days were selected as having a potential for severe thunderstorm winds over Southeast Florida. Ten dates had reports of non-tornadic severe thunderstorm winds. These dates are part of the eleven dates initially identified for use in establishing the model. Two other dates selected by the model had a

report of hail, and a tornado, and did not meet the criteria for a severe thunderstorm wind event. As expected, one date with a report of severe thunderstorm winds (23 June 1976) was not selected due to its relatively unique values of directional wind shear at TBW, and mean wind direction, especially at PBI. Ironically, these factors were later shown to be insignificant in the characterization of a pre-convective environment associated with reports of severe thunderstorm winds over Southeast Florida.

An attempt was made to apply a statistical test to all of the factors analyzed in this research. Logistic regression was employed to attempt to fit the observed data to a logistic function, as presented by Montgomery and Peck (1982). Logistic regression is similar to screening regression, as described by Glahn and Lowry (1972), since both procedures use binary or continuous predictors to statistically forecast the probability of a predictand, such as the occurrence of severe thunderstorm winds. Glahn and Lowry point out that probability estimates may not be as well behaved as when all predictors are binary. In this case, the 22 predictors employed in logistic regression were continuous, and the resulting probabilities produced by the procedure were not well behaved. For example, the statistical procedure identified the PBI MJLI as the most significant predictor, although the scatter plots showed that any decisional criterion for the variable could not be established. Glahn and Lowry also mention that an unstable system is likely, especially when the predictand is binary and when the climatological probability of the event is far from 0.5. Unfortunately, both conditions are applicable to this research. The

empirical probability of severe thunderstorm wind reports was so low that it was not possible to apply any significant statistical procedure to appropriate predictors.

4. INDEPENDENT TEST AND DEVELOPMENT OF A RELAXED MODEL

After developing a model which contained characteristic features of the pre-convective environment associated with non-tornadic severe thunderstorms, a trial run of the model was conducted using independent upper-air data from 1978, 1979, and 1981. In the 459 days represented by the new data, five dates were identified as having a report of non-tornadic severe thunderstorm winds over Southeast Florida using Storm Data. One additional report was not considered since it was associated with a tropical wave. The results of the independent test were quite disappointing. Various factors in the model were not satisfied for each of the five severe weather dates identified within the new time period. Also, the model selected four dates, none of which had a report of severe thunderstorm winds, although three had reports of waterspouts, funnel clouds, or lightning injuries associated with afternoon thunderstorm activity in the region.

An in-depth analysis was performed for the dates selected by the model, and the unselected dates with reports of severe thunderstorm winds. Synoptic charts were evaluated for each date and upper-air data were analyzed to see if other discriminating features were present. Analysis of the charts, upper-air data, and model factors' output showed that the model was too restrictive, but that the general synoptic conditions represented by the model were still present on all of the severe thunderstorm wind event days. Based on the results of the trial run, and analyses of upper-air data for several dates within the new time period, it was decided to try to "relax" the model such that the atmospheric conditions commonly present on all of the severe

thunderstorm wind event days would be represented.

a. Factors in the Relaxed Model

The relaxed version of the model included only the most significant, consistent, and useful factors from the original model. A mid-latitude trough, detected either at 600 or 500 mb, or northwesterly flow at 500 mb, was a feature found common on all of the days with a report of severe thunderstorm winds. The important part of this factor is emphasized to be northwesterly mid-tropospheric flow over the peninsula. Associated with the presence of northwesterly flow is the presence of relatively low values of θ_e in the mid-troposphere over TBW. Values less than 330 K were found between 650 and 500 mb at TBW on each day with a report of severe thunderstorm winds over Southeast Florida. Two examples of 500 mb charts associated with severe dates are shown in Fig. 20. Both cases represent similar, but contrasting, examples of wind flow from the northwest quadrant over a significant portion of the peninsula. Indications of cyclonic vorticity advection over southern Florida were quite variable among severe dates. Some cases, such as 23 August 1980, were similar to the 16 May 1985 case, where anticyclonic vorticity advection was indicated between an upstream ridge and a trough just off the east coast of Florida.

The vertical totals index for TBW and PBI exceeded the critical value of 23 on each severe weather event day, so the vertical totals index was also kept in the relaxed version. Values of the lifted index for PBI continued to be less than or equal to -3. For the purposes of indicating some homogeneity in the stability of the air mass over the peninsula, the TBW lifted index also remained in the relaxed model,

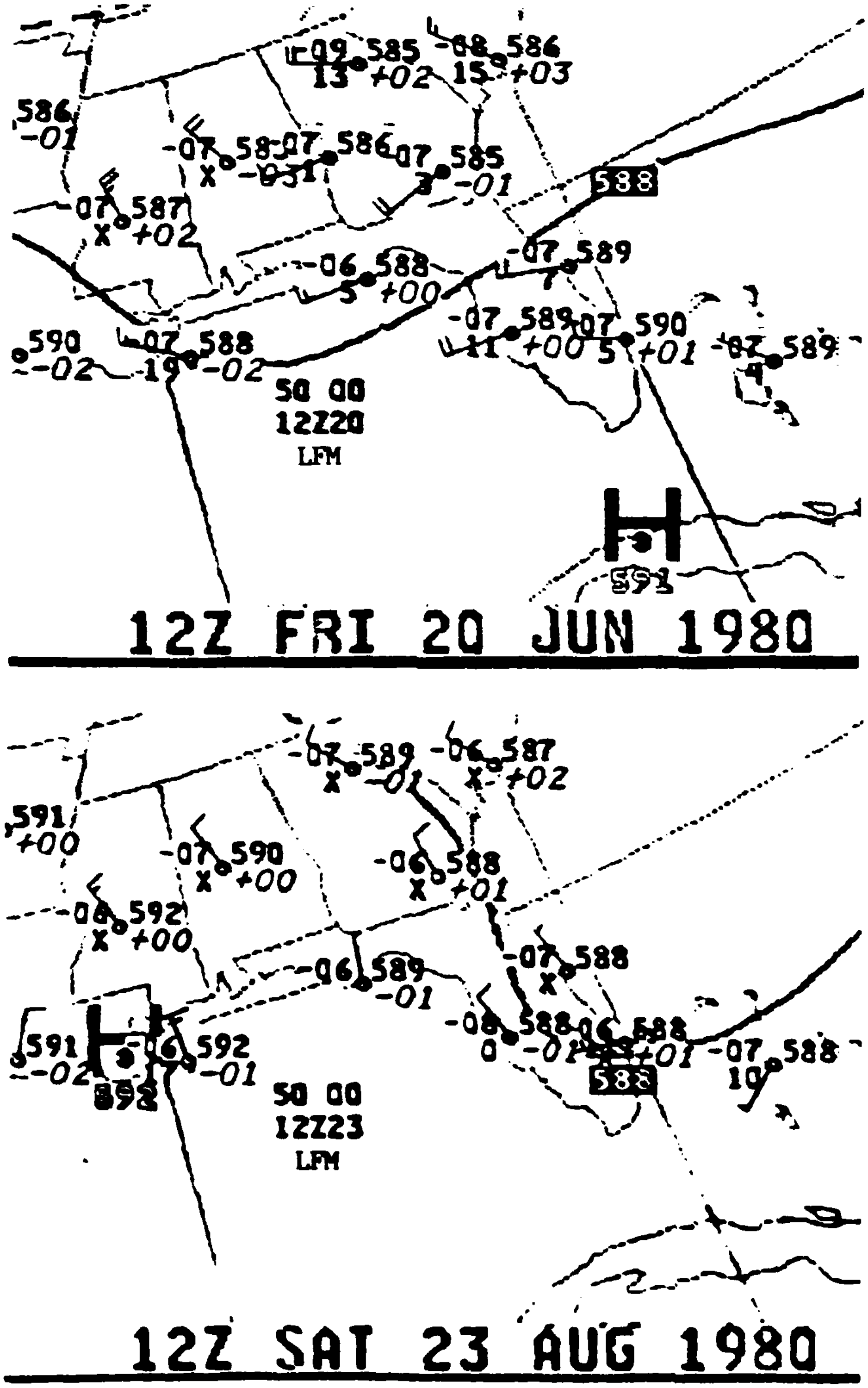

Fig. 20. Example of 500 mb charts associated with two severe thunderstorm wind events. Both charts illustrate the presence of northwesterly flow over a significant portion of the southern Florida peninsula.

although it is not considered as significant a factor as the other factors in the model. The lifted index at TBW was found to have values of 0 or less on all severe weather event days.

The PBI directional wind shear factor was adjusted slightly to account for one date where the directional wind shear was 50^{o}. Otherwise, all other severe thunderstorm wind events were partially distinguished by directional wind shears of less than 45^{o}. Table 4 lists all of the factors and their critical values, if applicable, which were incorporated into the relaxed model.

b. Calculation of Convective Available Potential Energy (CAPE)

The usefulness of the vertical totals and lifted indices indicated that low-level warm, moist air and relatively cool air aloft were significant features on all of the days with reports of severe thunderstorm winds. The latent and thermal instability present prior to each severe thunderstorm wind event suggested that calculation of the amount of positive area on the upper-air soundings might provide an additional distinction for severe thunderstorm wind events. Calculations of Convective Available Potential Energy (CAPE) were made to obtain a quantitative measurement of the amount of positive area present in the upper-air sounding. CAPE was computed by vertically integrating the difference of environmental potential temperature from the potential temperature of a parcel lifted pseudo-adiabatically from the LCL, between the level of free convection (LFC), and the equilibrium level. From the LFC to the point where the ascending parcel again becomes equal in temperature to its surroundings, called the equilibrium level, the atmosphere is characterized by latent

Table 4. Factors and their critical values used in a relaxed model to indicate a potential for severe thunderstorm winds over Southeast Florida. All values are ^{o}C, unless otherwise indicated.

FACTOR		CRITICAL VALUE
TBW and PBI 500 or 600 mb Mid-Latitude Trough or 500 mb NW Flow		
TBW Minimum Equivalent Potential Temperature (650 - 500 mb)		$<$ 330.0 K
PBI Directional Wind Shear (950/900 - 550/500 mb)		$\leq 50^{o}$
PBI Vertical Totals	TBW Vertical Totals	$\geq$ 23.0
PBI Lifted Index		$\leq$ -3.0
TBW Lifted Index		$\leq$ 0.0

instability. Throughout this region, considered the positive area, the parcel will gain kinetic energy as it rises. The CAPE represents the amount of work per unit mass done by the environment on an air parcel which rises from its level of free convection to its equilibrium level (Bluestein and Parks, 1983). The CAPE was calculated using the expression

$$\text{CAPE} = \int_{z_1}^{z_2} g(\theta_c - \theta_{env})/\theta_{env} \, dz,$$

where θ_c is the potential temperature of a saturated air parcel originating from the LCL lifted pseudo-adiabatically, θ_{env} is the potential temperature of the unsaturated environment, z_1 is the height of the LFC, and z_2 is the height of the equilibrium level. During calculation of the CAPE, minor inversions below 700 mb were interpreted by the computer program as equilibrium levels. To allow for

calculation of a more representative CAPE value, it was assumed that a rising, saturated air parcel would overcome inversions below 700 mb if having enough positive buoyancy. Therefore, the calculation of CAPE continued if the positive buoyancy of a parcel exceeded the negative buoyancy indicated by the inversion.

Fig. 21 shows a plot of CAPE versus the lifted index for PBI. There is a considerable amount of positive area calculated on almost every day. The plot also reveals a linear equivalence between the two variables. This linearity is not surprising since both variables use equivalent methods of calculating their respective values. Since the CAPE appeared to have a high degree of correlation to lifted index values, as illustrated by Fig. 21, there was no additional usefulness derived from the CAPE in providing any indications of severe thunderstorm winds. Furthermore, there is roughly a three-fold variation in magnitude among all the severe dates.

c. Evaluation of the Relaxed Model

The relaxed version of the model was tested using all 918 days of data. The results were mixed. All 16 dates with a report of severe thunderstorm winds were selected by the model. However, 38 additional dates were selected, seven of which had reports of other severe thunderstorm activity in Southeast Florida. Although the model is intended for detecting the potential for non-tornadic severe thunderstorm wind events over Southeast Florida, a few indications of the potential for these storms could be equated to reports of other severe thunderstorm activity over the same region. The total selection of 54 days out of 918 days (5.9 %) represents a considerable advance in

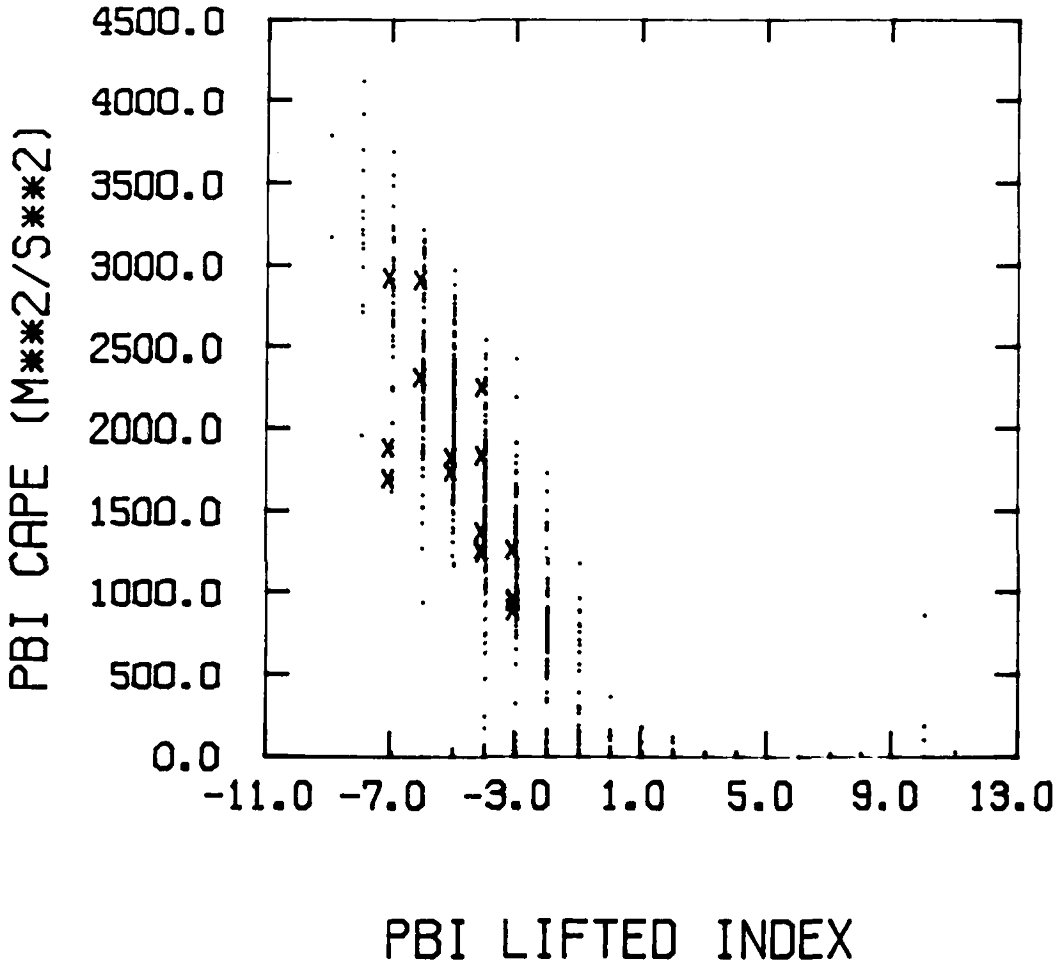

Fig. 21. Scatter plot of PBI LI (^{o}C) versus PBI CAPE (m^2 s^{-2}) for the period of May through September of 1976-1981. Each day is represented by the plot of a point. Each "X" indicates a day with a report of severe thunderstorm winds. Each point or "X" may represent more than one day.

the forecasting of severe thunderstorm potential, considering that well over 50 % of the days within the period of May through September experience thunderstorm development over Southeast Florida (Reap and Foster, 1975).

Results of the test were also evaluated for the period of June through August when daily thunderstorm activity is at its peak, and organized synoptic systems rarely exist over South Florida (Frank et al., 1967). During this time period, the model performed much better; 31 days were selected by the model as having a potential for damaging surface winds from thunderstorms over Southeast Florida. Sixteen (51.6 %) of the 31 days had a report of severe thunderstorms, including tornadoes, while 13 days (41.9 %) had reports of non-tornadic severe thunderstorm winds. The results of the model during June through August are even more pleasing considering that almost every day during this time period has a significant possibility of thunderstorm development over Southeast Florida. Obviously, the relaxed model has a higher false alarm rate during May and September, which typically are transition months between the presence of organized synoptic-scale weather systems, and the relatively undisturbed climate dominated by the sea breeze circulation. It is not known how many actual severe thunderstorm wind events did occur over Southeast Florida from 1976 to 1981, although it is likely that many more occurrences of severe weather existed than were reported in Storm Data. Although the model selected some dates with reports of other severe thunderstorm activity, it did not select enough dates to be considered applicable to all cases of severe thunderstorm activity.

5. SUMMARY AND RECOMMENDATIONS

The intention of this research was to develop a model, incorporating factors which were indicative of the potential for non-tornadic severe thunderstorm winds over Southeast Florida. Analyses of scatter-plot graphs representing many atmospheric variables and features led to the development of a set of conditions which characterize a pre-convective synoptic environment commonly associated with severe thunderstorm wind events over Southeast Florida. The pre-convective environment can be viewed as a typically warm, moist, and unstable atmosphere which has little directional wind shear between the gradient level and the mid-troposphere. The mid-troposphere is characterized by northwesterly flow across a significant portion of the peninsula accompanied by an advection of potentially cool, dry air from the northwest into the southern part of the peninsula, as indicated by a minimum θ_e value less than 330 K between 650 and 500 mb at TBW. A critical underlying assumption of the model is that the sea-breeze circulation is present over the peninsula, since it provides the initial trigger mechanism for the thunderstorms.

It is interesting to note that a few of the features characteristic of the pre-convective synoptic environment associated with severe thunderstorm winds over Southeast Florida are similar to common synoptic features present on dry microburst days at Denver (Wakimoto, 1985). Wakimoto found that a weak surface front was near Denver during the day, a weak to moderate 500 mb trough was northwest of the region with little or no positive vorticity advection present over Denver, and the upper-level winds were less than 26 m s^{-1} (50 kt),

with the exception of one day.

The final form of the model represents a less-stringent version of a model developed from initial analyses of three seasons of data. The relaxed model is simpler, and contains fewer factors than the initial model which was found to be too restrictive when applied to independent data. The factors retained in the relaxed model were given in Table 4. The model selects a date as having the potential for severe thunderstorm winds only if all of the factor criteria are satisfied. The model utilizes 1200 GMT upper-air data from only two upper-air stations, PBI and TBW. The simplicity of the model is designed to give forecasters a quick and easy initial look at the potential for severe thunderstorm winds. The model is not intended to be used by itself, but instead should be viewed as an aid to forecasters. Local analyses of streamline charts, and satellite and radar data should be fully utilized before relying on the results of the model.

Application of the model to six seasons, or 918 days, showed that the model accounted for environmental conditions preceding every report of severe thunderstorm winds over Southeast Florida, and performed best during months in which organized synoptic activity was limited, based upon non-tornadic severe thunderstorm wind reports. Although the model did not produce perfect results, it was realized that production of a perfect model would be impossible, since surface reports of severe weather, used in both establishing and evaluating the model, were very subjective and did not reflect all of the occurrences of severe thunderstorm winds. Despite the unreliability of surface storm reports used to identify the occurrence of a severe thunderstorm wind event, it

is anticipated that the current form [illegible] to most, if not all, cases of severe thunderstorm [illegible] Southeast Florida, not associated with [illegible] systems. For the purpose of independent testing [illegible] it would be most ideal to [illegible] test the model [illegible] intense program designed to [illegible] reports [illegible] storm surveys over Southeast Florida.

Future use and study of the model presented here [illegible] some modifications. While critical values [illegible] indicate a positive or negative potential of severe thunderstorm [illegible] it may be possible to develop a probabilistic model [illegible] factors and provides a probability of severe thunderstorm [illegible] southeast Florida. It may also be possible to construct a [illegible] tree representing an appropriate stepwise progression [illegible]. Another approach would be to scale all of the factors in the model and combine them to form an index, similar to the Johnson Lag index described earlier, indicative of the potential for severe thunderstorm winds. It is anticipated that any modification of the model, although perhaps more useful, would require some type of factor analysis more in-depth than what has been presented here.

Some of the general features represented by the model could possibly be applied to other areas of the peninsula, and to other types of severe thunderstorm events. The model was representative of significant events such as the 1980 Memorial Day Weekend Severe Weather Outbreak, when extensive severe weather was reported statewide. In addition, 30 June 1980 was identified as a potential day for severe

[illegible] severe storm reports were received in [illegible] AFB, also along the east coast, [illegible] damaged five tied down [illegible] another area would likely rely [illegible] here, and other features, [illegible] upper air data [illegible].

[illegible] the use of a third [illegible] northwest), of the [illegible] station might include [illegible] takes upper air observations at 1200 [illegible] water satellite sounding. The triangle of [illegible] such as vorticity and [illegible] these calculations [illegible] wind events would yield more [illegible] inferred from synoptic charts alone.

[illegible] be made, more knowledge has to be [illegible] nature of severe thunderstorms, and [illegible] the multi-scale interactions taking [illegible] many meteorological phenomena over Florida [illegible] models, theories, and observations [illegible] areas which may not necessarily apply to [illegible]. An observational field experiment designed for [illegible] Florida, but larger in scope than the FACE program, could enhance and improve our knowledge of a wide variety of atmospheric phenomena such as severe and non-severe thunderstorms, wet downbursts, the sea-breeze circulation, frontal rope clouds, tropical waves and

cyclones, and lightning. It is hoped that this research will lead to a better understanding of the preferred environment in which non-tornadic thunderstorms produce severe damaging surface winds over the Florida peninsula.

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VITA

Jeffrey Michael Wilhelm was born in Chicago, Illinois on March 21, 1961, one-half month after a devastating tornado struck the south side of Chicago. His parents are Ernest O. Wilhelm, Jr. and Marlene F. (Ebel) Wilhelm. Jeff is the oldest of seven children. He grew up in the Chicago metropolitan area, and graduated from Hinsdale South High School in Darien, Illinois, in 1979.

From August 1979 to May 1983, he attended the University of Oklahoma where he received a Bachleor of Science degree in Meteorology. While attending the University of Oklahoma, he worked for one year at the National Severe Storms Laboratory, in Norman, as a Meteorological Technician, or Student Assistant. Upon graduation, he was commissioned a Second Lieutenant in the United States Air Force. He was assigned to Homestead AFB, Florida, in June 1983 where he served as the Wing Weather Officer. From August to October of 1984, Jeff also had the opportunity to serve as a temporary weekend weather forecaster at WCIX-TV in Miami, Florida. He was promoted to First Lieutenant in June 1985. Soon afterward, he left Florida to attend Texas A&M University and pursue a Master of Science degree in Meteorology, under the auspices of the Air Force Institute of Technology.

Jeff married the former Grace Elisabeth Heumann, of Pembroke Pines, Florida, in April of 1985. His permanent mailing address is: 4233 Van Buren St, Hollywood, Florida 33021.

The typist for this thesis was the author.

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